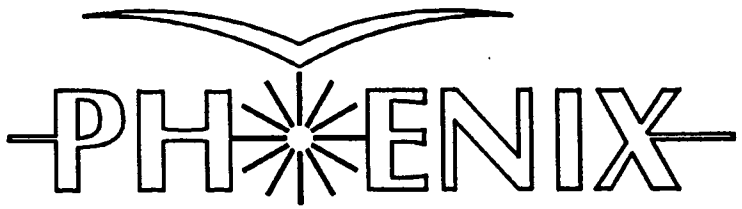
RHIC/PHENIX Detector



Central Magnet and Muon Subsystem Steel Final Design Review

Joel Bowers
Palmer House

Lawrence Livermore National Laboratory
August 2, 1993

JMB
7/28/93

Agenda

Muon subsystem

Lunch

Central magnet

Dinner

Schedule
Procurement plan
Open issues

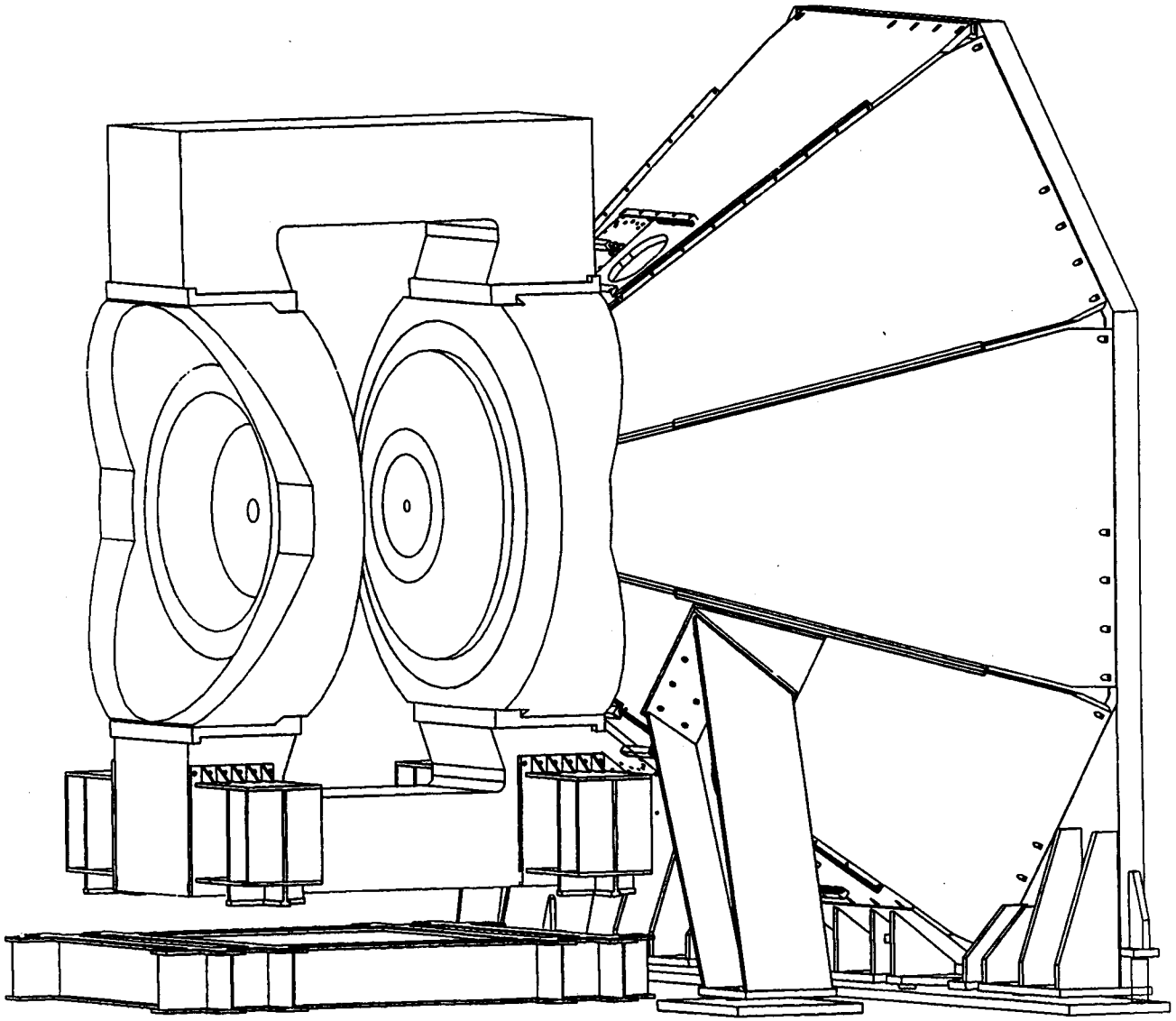
Purpose of this review

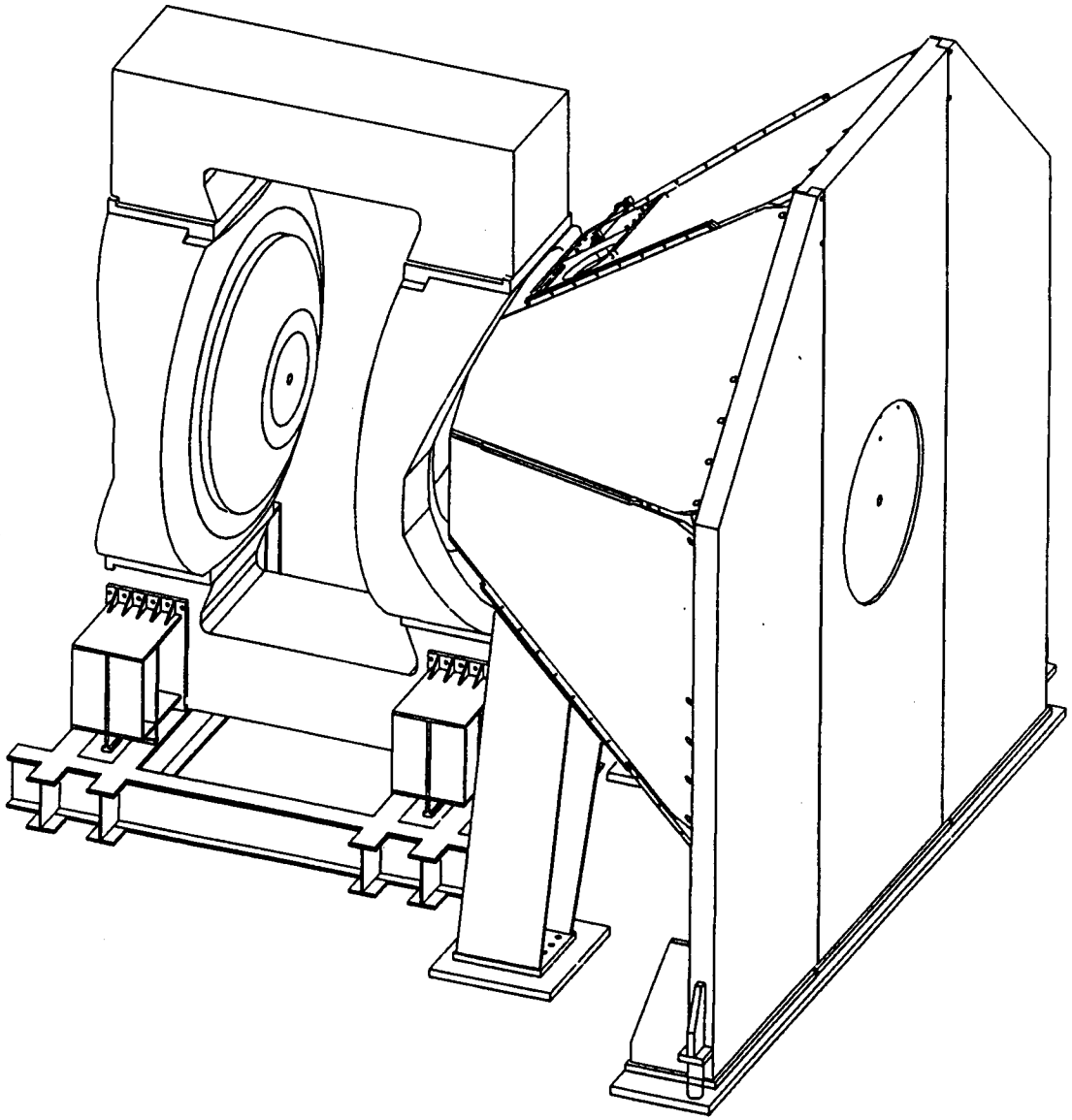
- Verify form and function of Phenix magnet steel
- Obtain commitment on final design changes
- Obtain approval to complete detailed design package
- Obtain approval proceed with procurement
- Resolve action items from Preliminary Design Review

Key contributors to the magnet steel effort

Rudy Carpenter:	quotes, vendor research
Ed Dalder:	metallurgical advice
Bob Highland:	design
Bob Holmes:	design
Larry Mullins:	design
Joe Ryland:	quotes, vendor research

JMB
7/28/93


Y
Z
X


Y
Z
X

Focus of design efforts since PDR

- Detail drawing preparation of June design
- Detail checking
- Additional design work on guided door
- Accomodation of Efremov design changes on CM
- Accomodation of BNL design changes on MM
- Interference checking

Mechanical requirements

Central Magnet and Muon Subsystem

1 Provide field shaping and flux return

2 Provide structural support for detectors

3 Lift and transport for upgrades and maintenance (Central Magnet only)

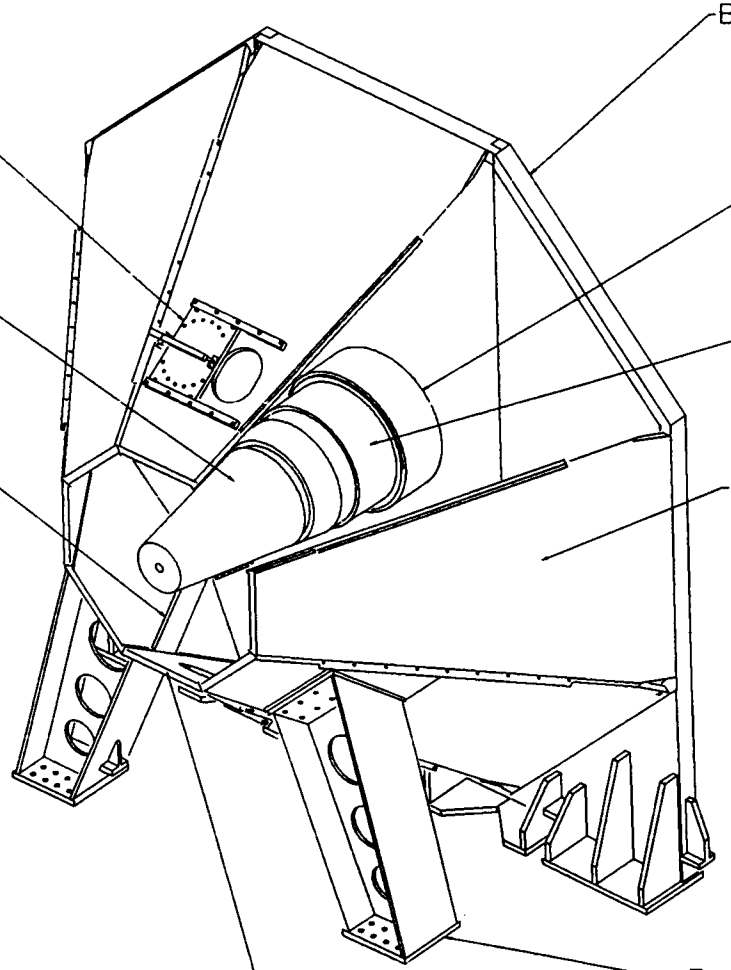
5 Maximize stability within space constraints

6 Meet seismic safety requirements for Brookhaven (from UBC & UCRL 15910: Vertical 0.1g, Horizontal 0.15g)

7 Minimize on-site construction time

8 Alignment capability

Muon Magnet Assy. — Approx. Weight



Coil 1	941
Coil 2	1087
Backplate Assy.	216967
Piston	54335
(7) Upr Lampshd Pnls	63147
Lwr Lampshd Pnl	6387
(2) Piston Supt Fins	944
(2)Front Supports	9564
(3) Access Doors	2172
TOTAL	355544 Kg (787,530 lbs)

Muon Subsystem component weights

June Design
(Approximate)

Item	Quantity	unit weight	total weight
Lampshade plate	8	10	80
Piston core	1	60	60
Support legs	2	6	12
Back plate	1	239	239
Access doors	3	1	3
Stabilizer fins	2	0.5	1
Coils	2	1	2
		total weight:	397 tons
		design weight:	500 tons

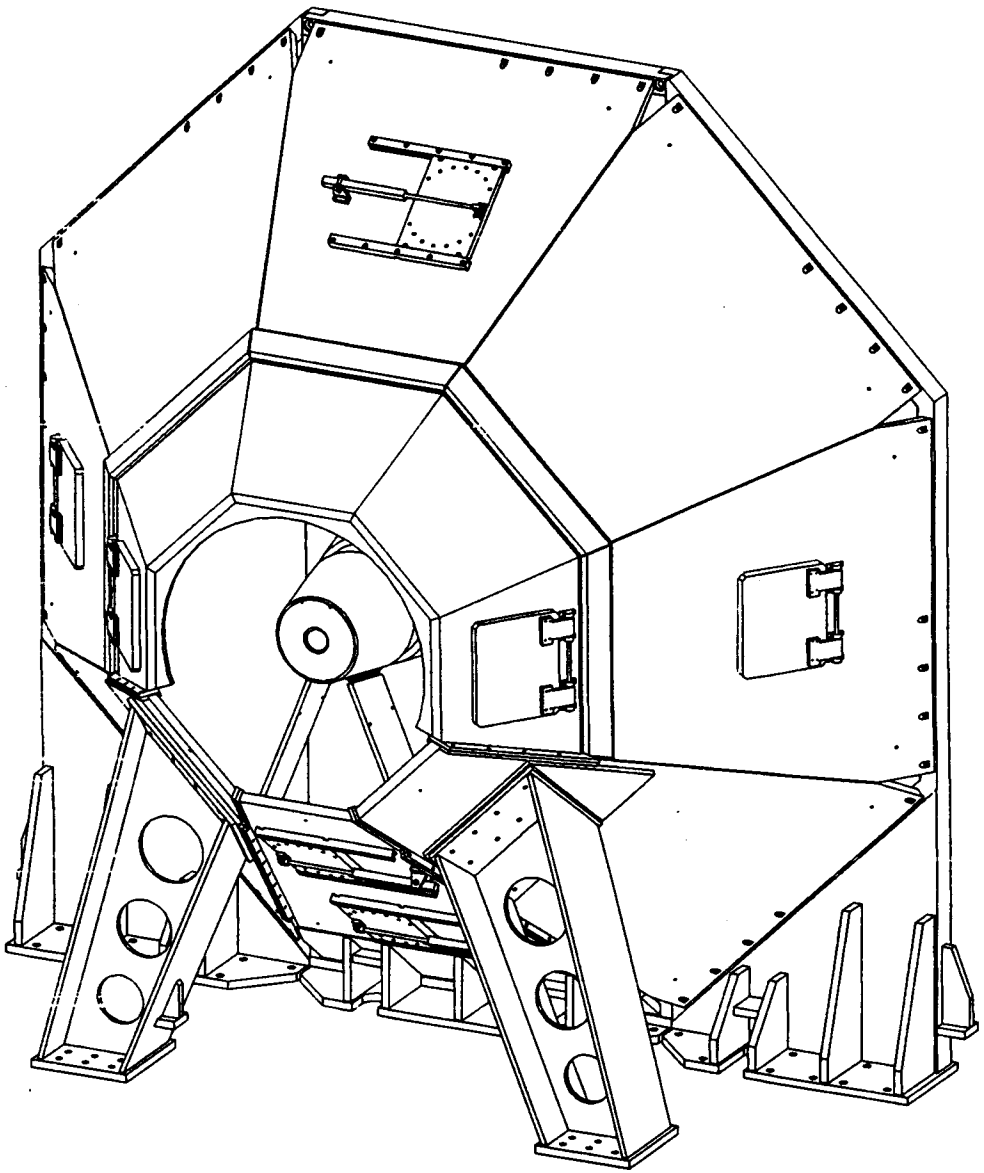
JMB
7/28/93

Effect of July design changes

- bottom three lamp shade plates are unchanged
- no significant change in total weight

Item	Quantity	unit weight	total weight
top five lampshade plates	5	8	40 tons
5 sided teacup	1	12	12 tons

JMB
7/28/93



Primary design features (July design)

- Top 5 plates (8 tons each) removable
- Semi fixed section of top lampshade (tea cup)
- Hydraulic drive access doors on top and bottom plates
- Hinged access doors on side plates
- Removable stabilizer fins minimize muon piston motion
- Piston coils can be installed after steel installation
- Jacking points provided for alignment
- Conventional (but challenging) fabrication techniques
- 100% off site fit verification

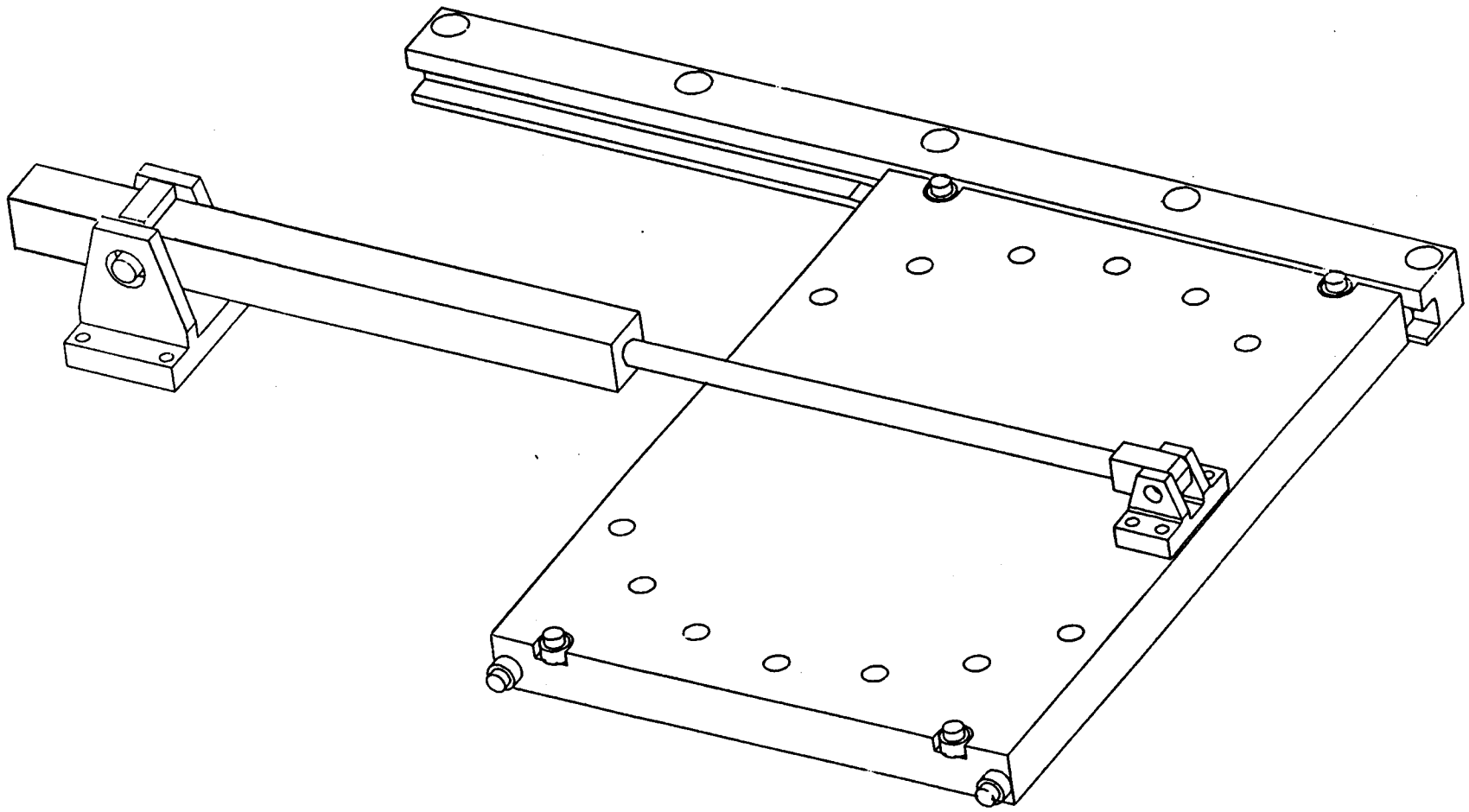
Access doors

- Each door weighs about 1400 pounds
- Overlap on lampshade is 160mm in Z, 80mm in X

Hydraulic, track guided (3 total):
- Two on bottom, one on top
- Hand pumped hydraulic cylinder drives each door
- Door moves horizontally, captured in guide tracks
- Horizontal motion is inherently safe, requires low force
- Doors move on precision cam rollers, backed by safety pins

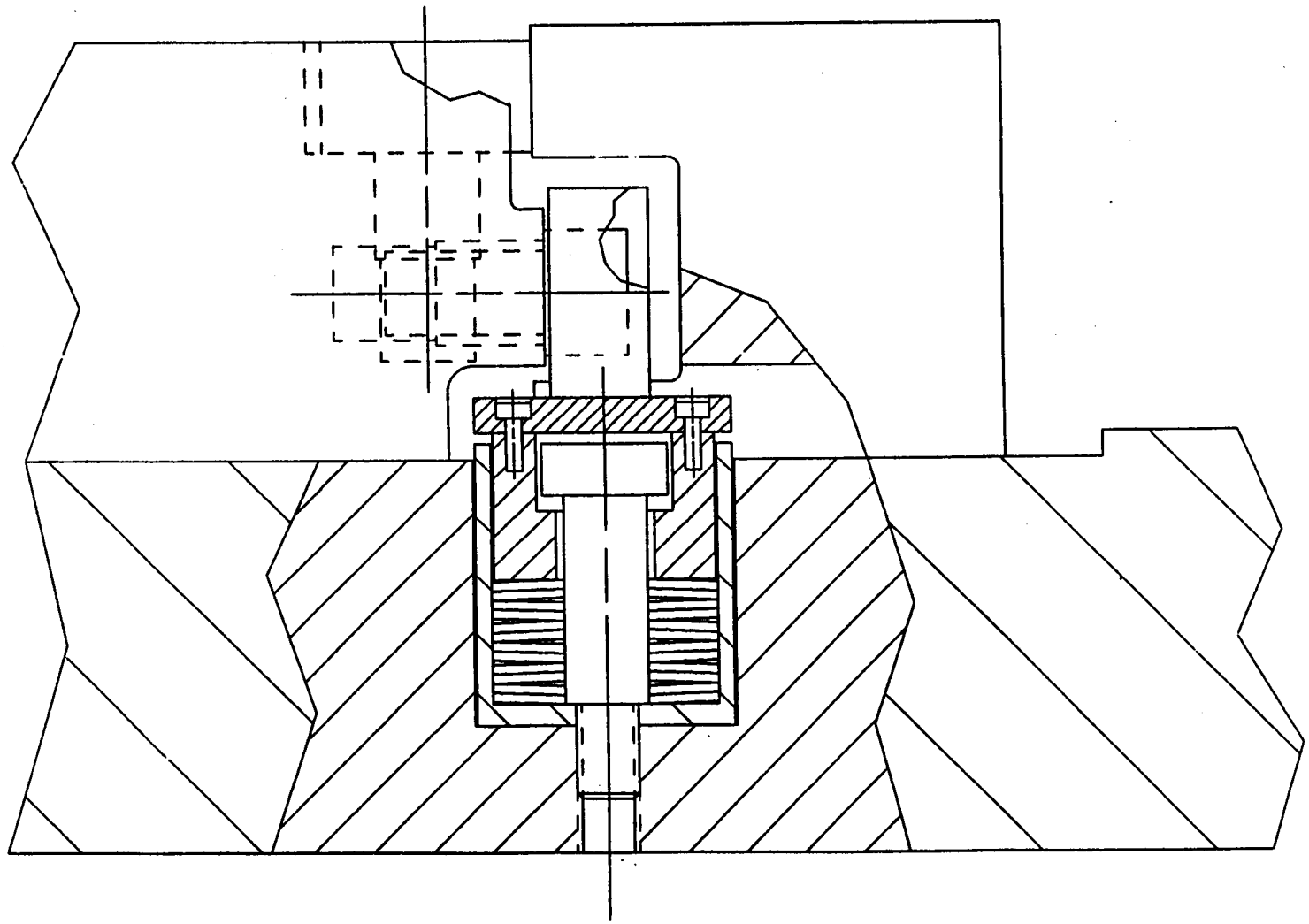
Manual, Hinged (4 total):
- Two on teacup sides, one on each side lampshade plate
- Needs to be seismically anchored when open
- Uses flexible hinge to assure proper seating

Cam roller guided door



Cam roller guided door: compression detents

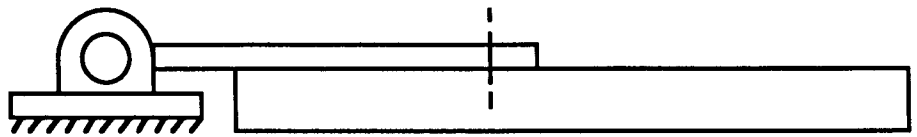
- Spring loaded plate allows rollers to sink below the track
- Magnetic contact between the door and lampshade is assured



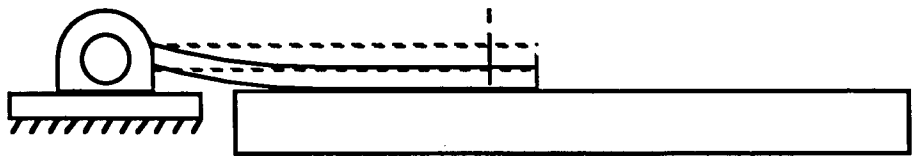
JMB
7/28/93

Flexible hinged Door

- Hinge when door just touches lampshade



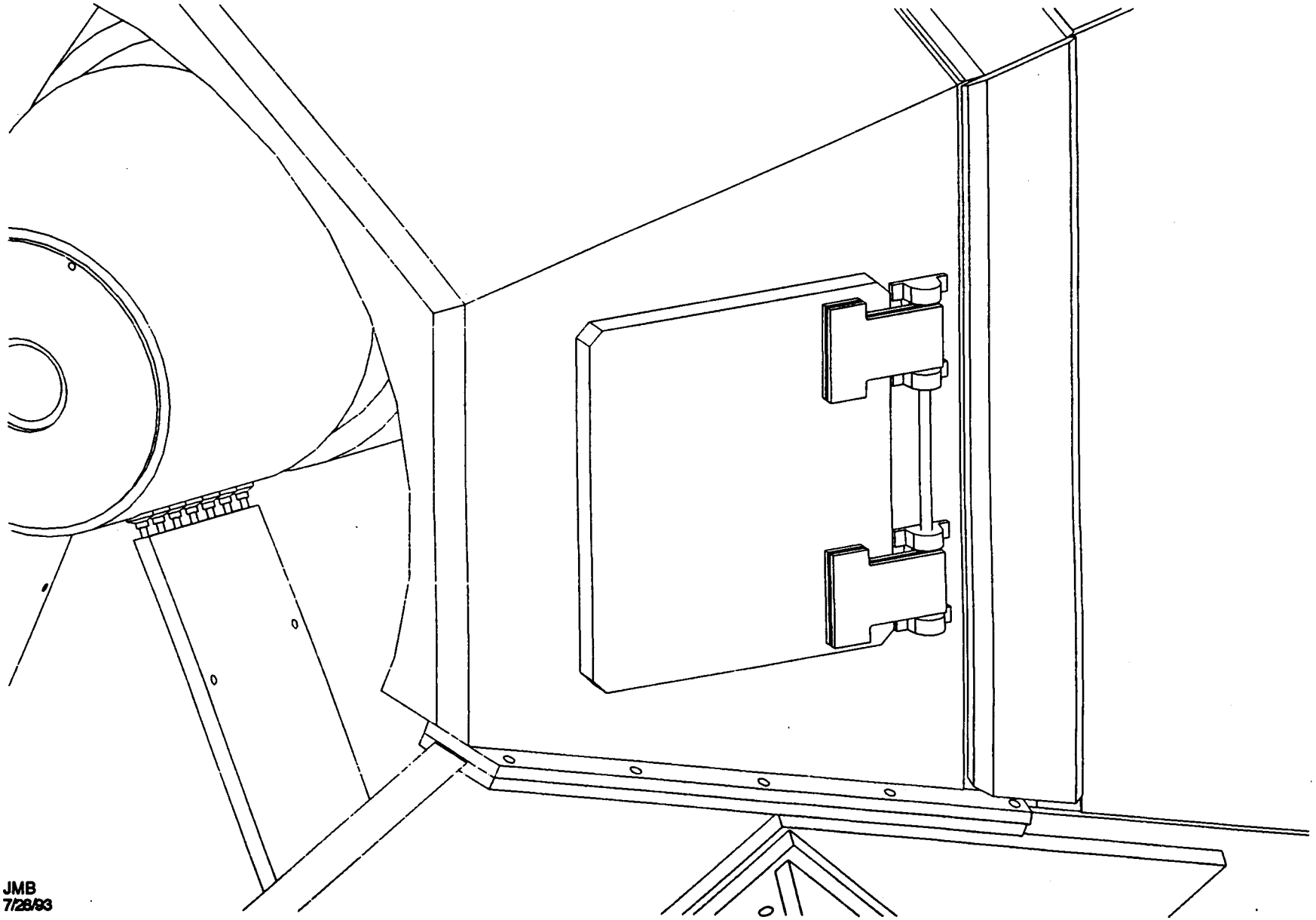
- Hinge when door makes solid contact after bolting



This concept has been used extensively on vacuum vessels at LLNL for the Atomic Vapor Laser Isotope Separation (AVLIS) project. Phenix can use the AVLIS drawings unmodified for this hinge design.

JMB
7/28/93

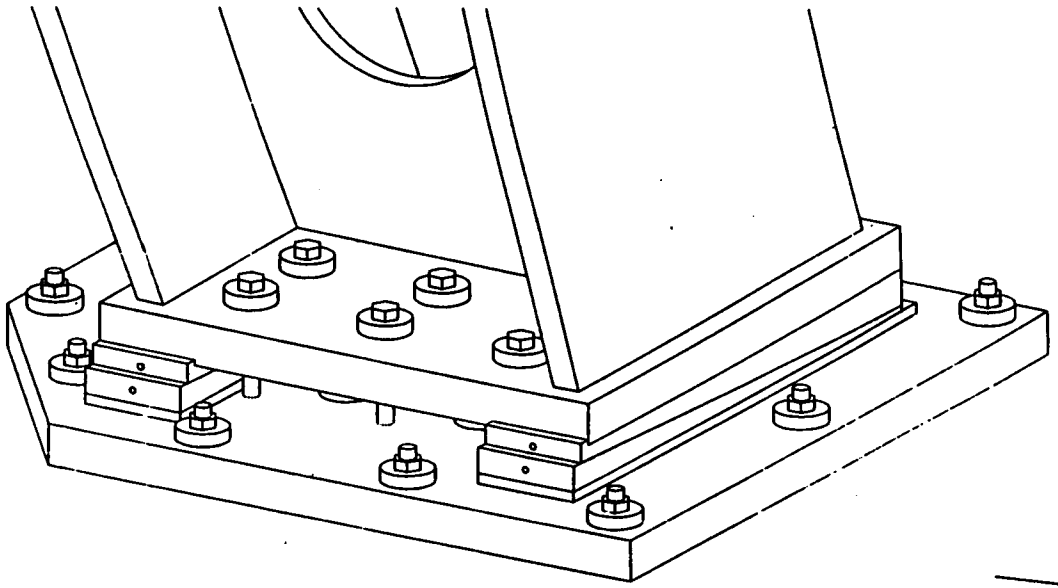
Hinged door assembly

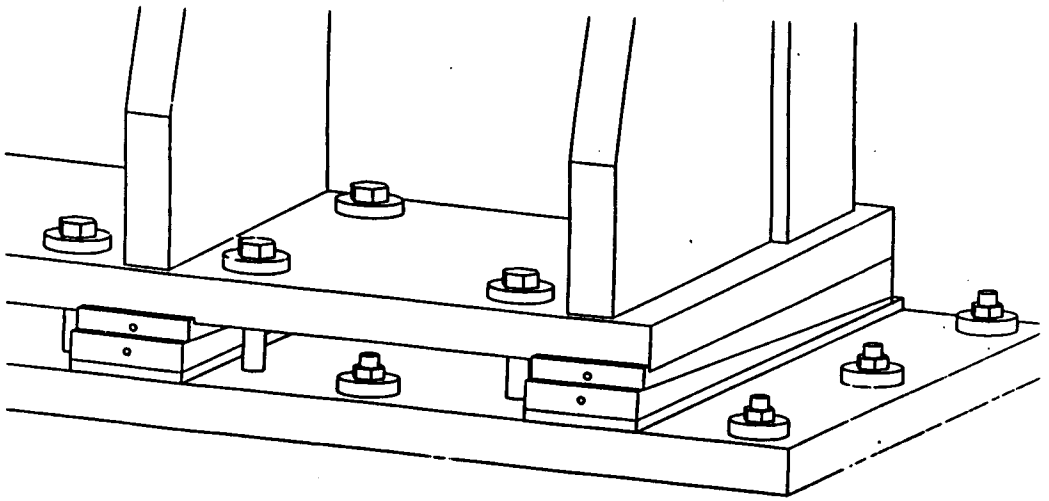


JMB
7/28/93

Muon system floor anchorage

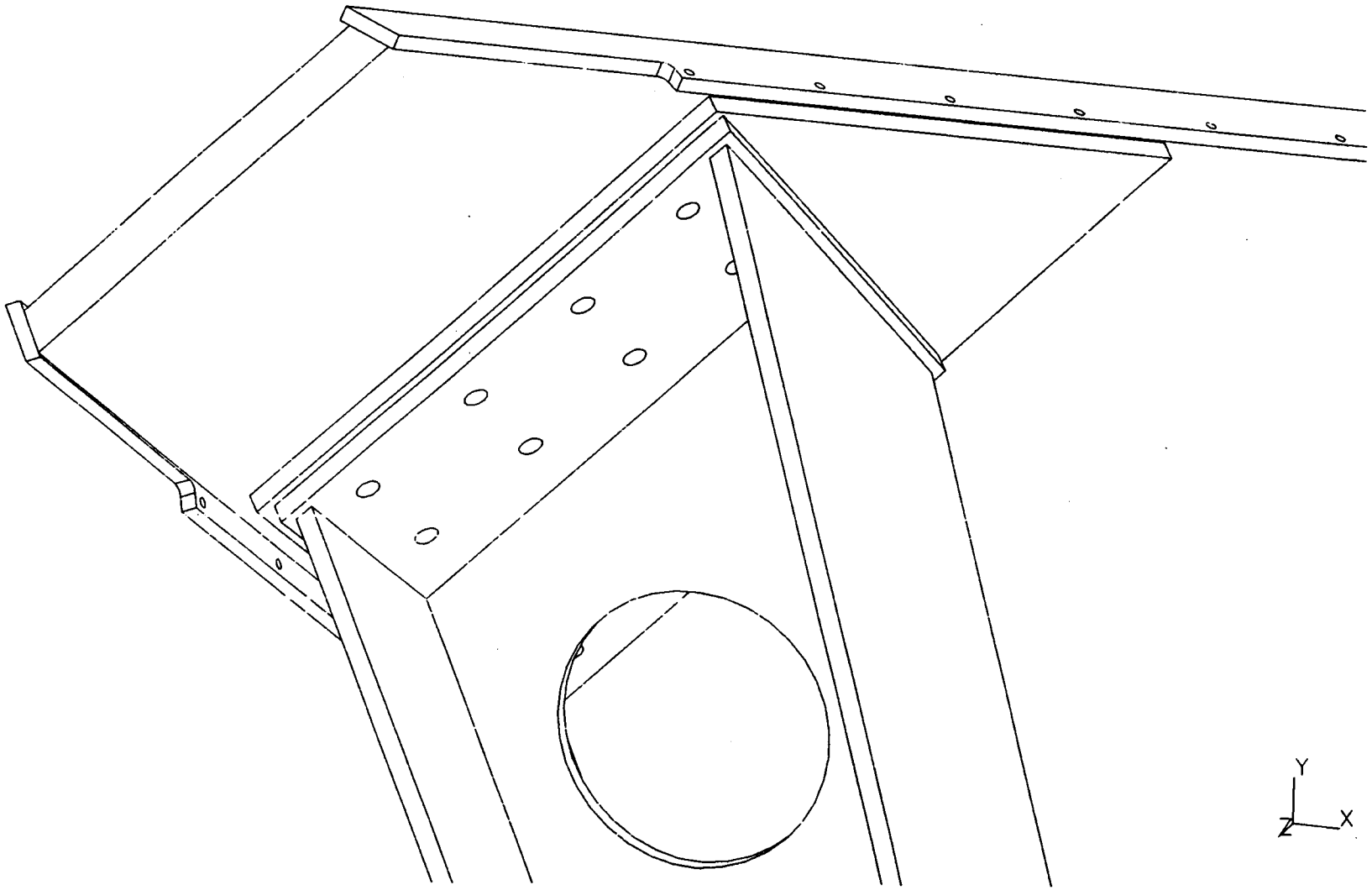
- Foundation plates anchored and grouted to floor
- Tapped holes provided to mount detector on studs
- Detector shimmed to foundation plates with wedges

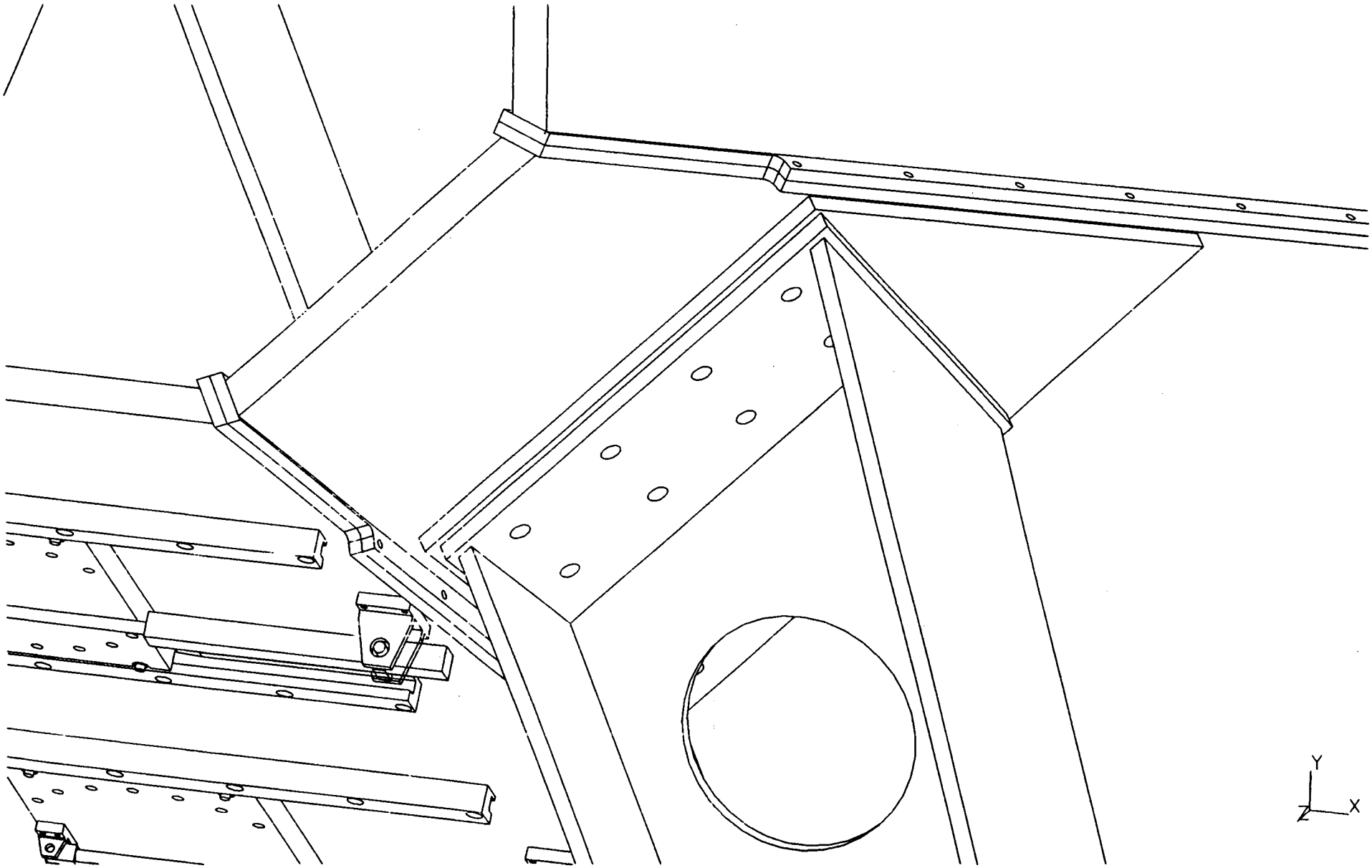




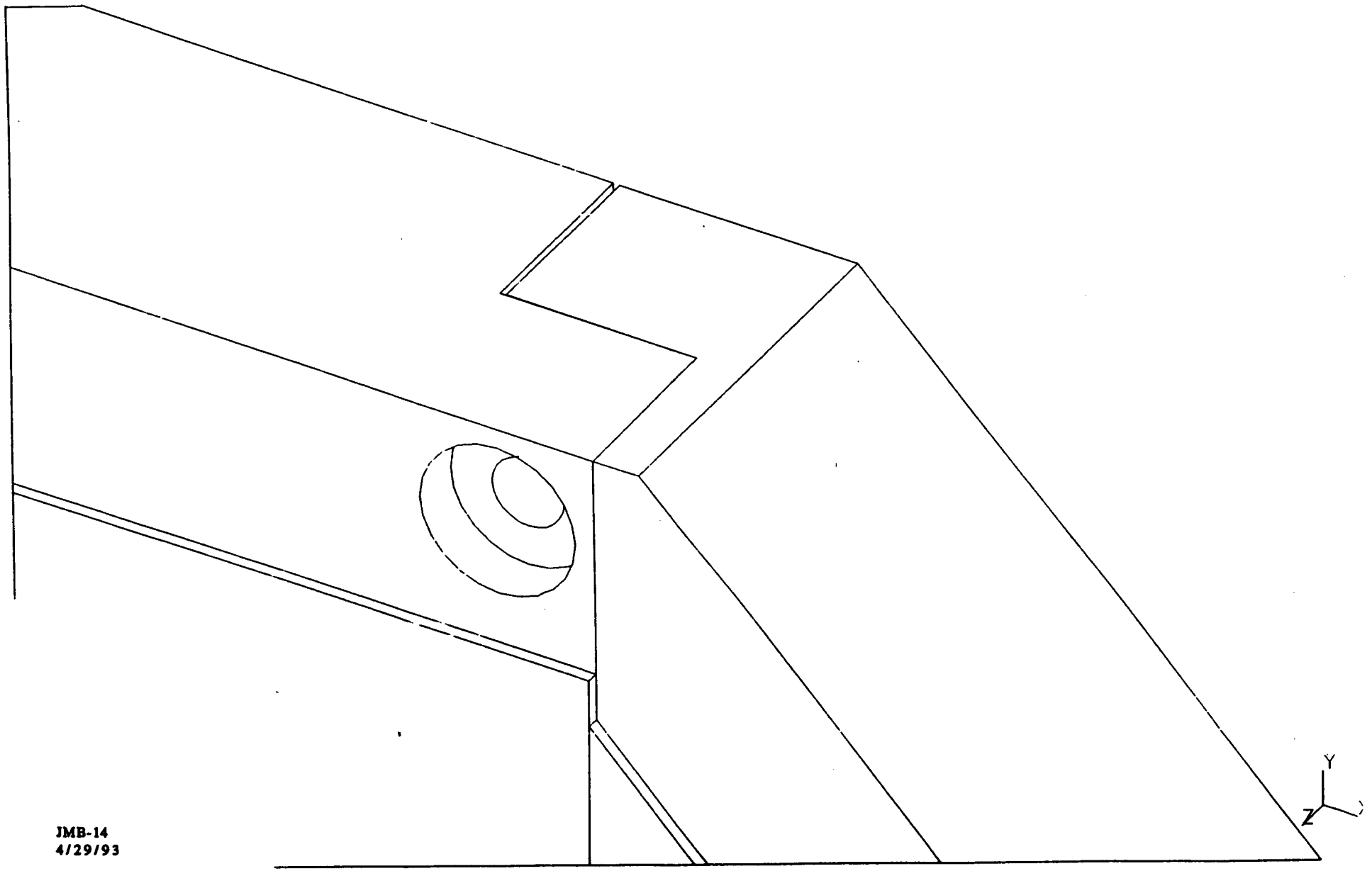
JMB
7/28/93

Lampshade-front leg connection

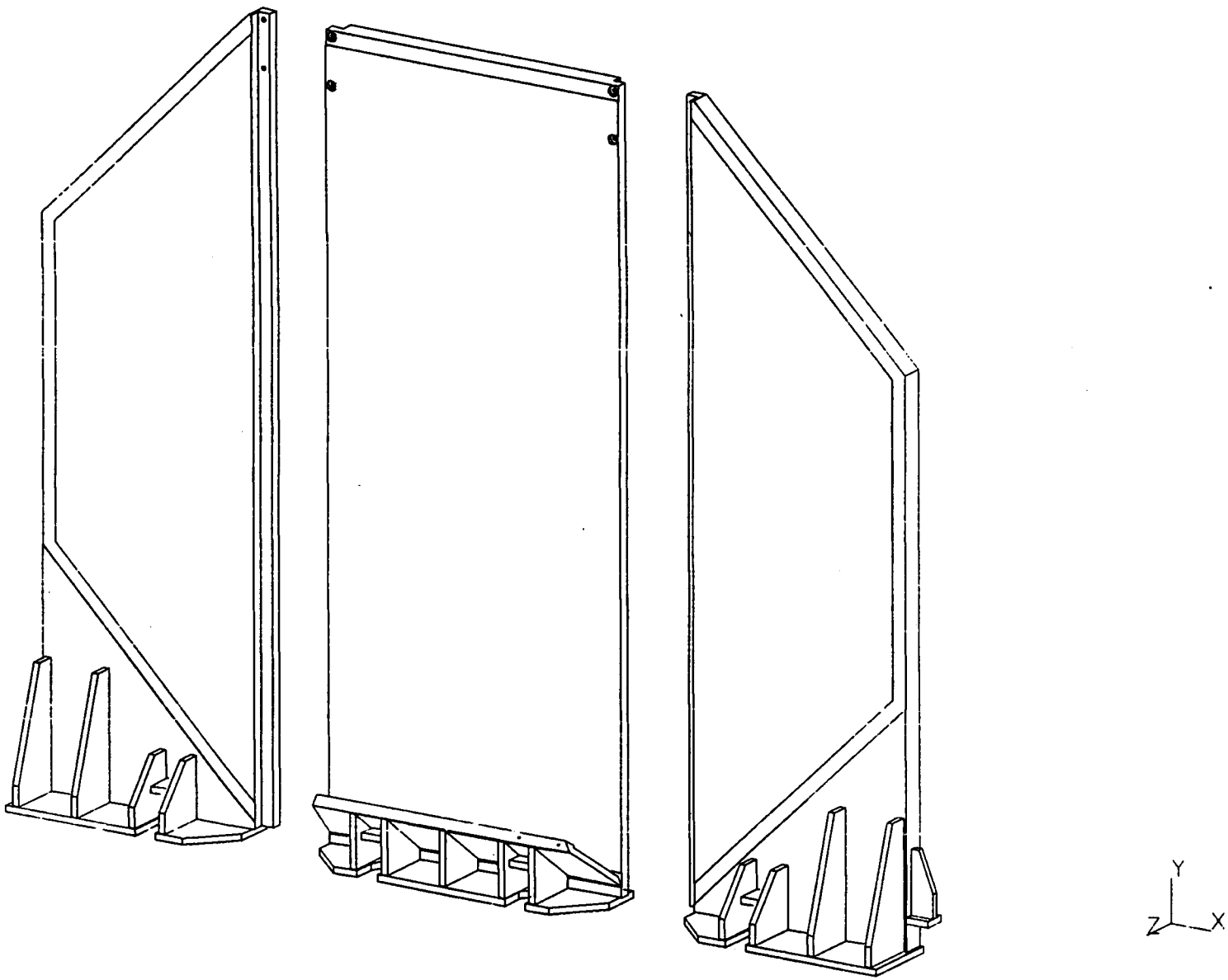



Y
X
Z

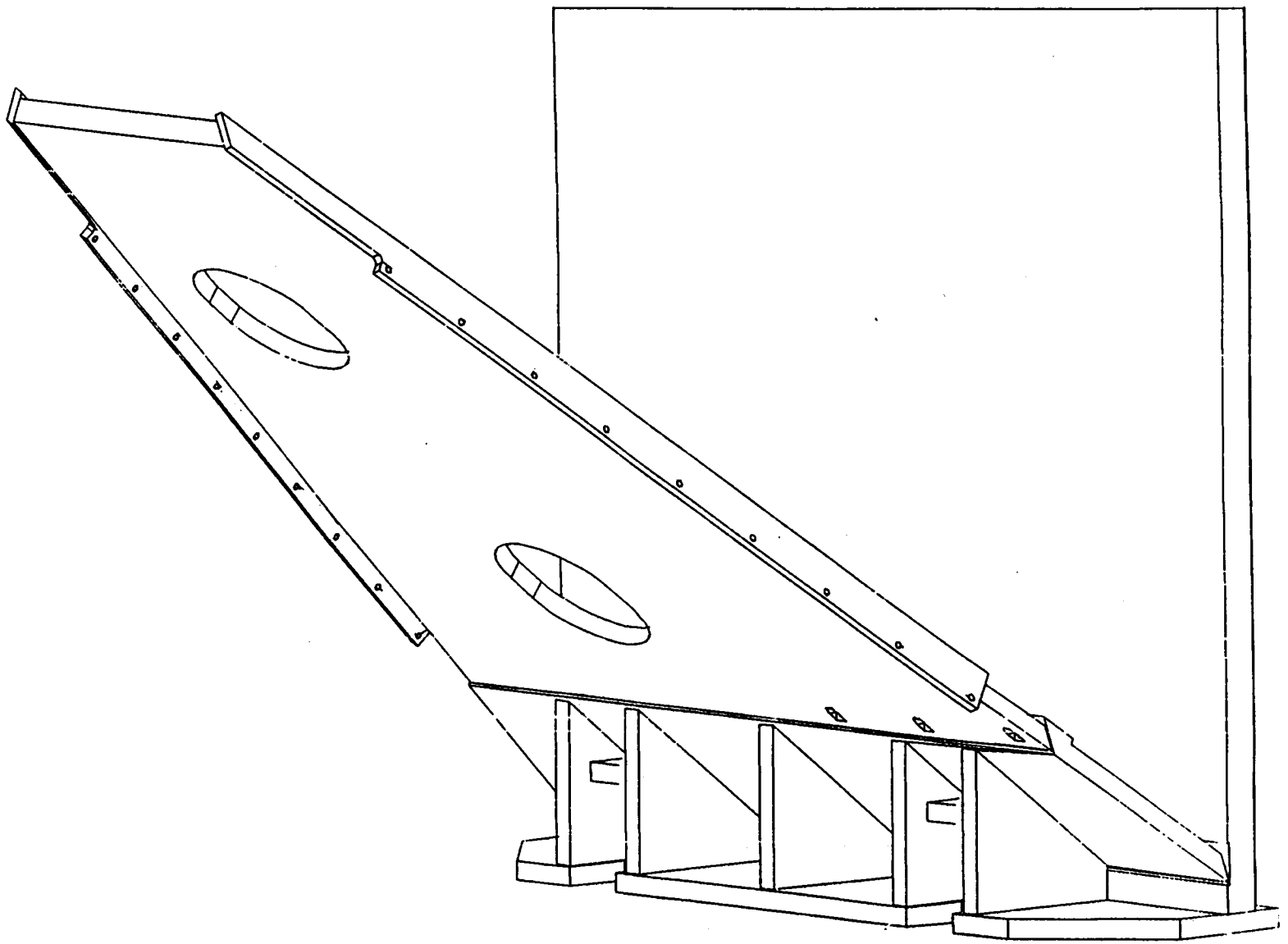
Backplate-backplate connection

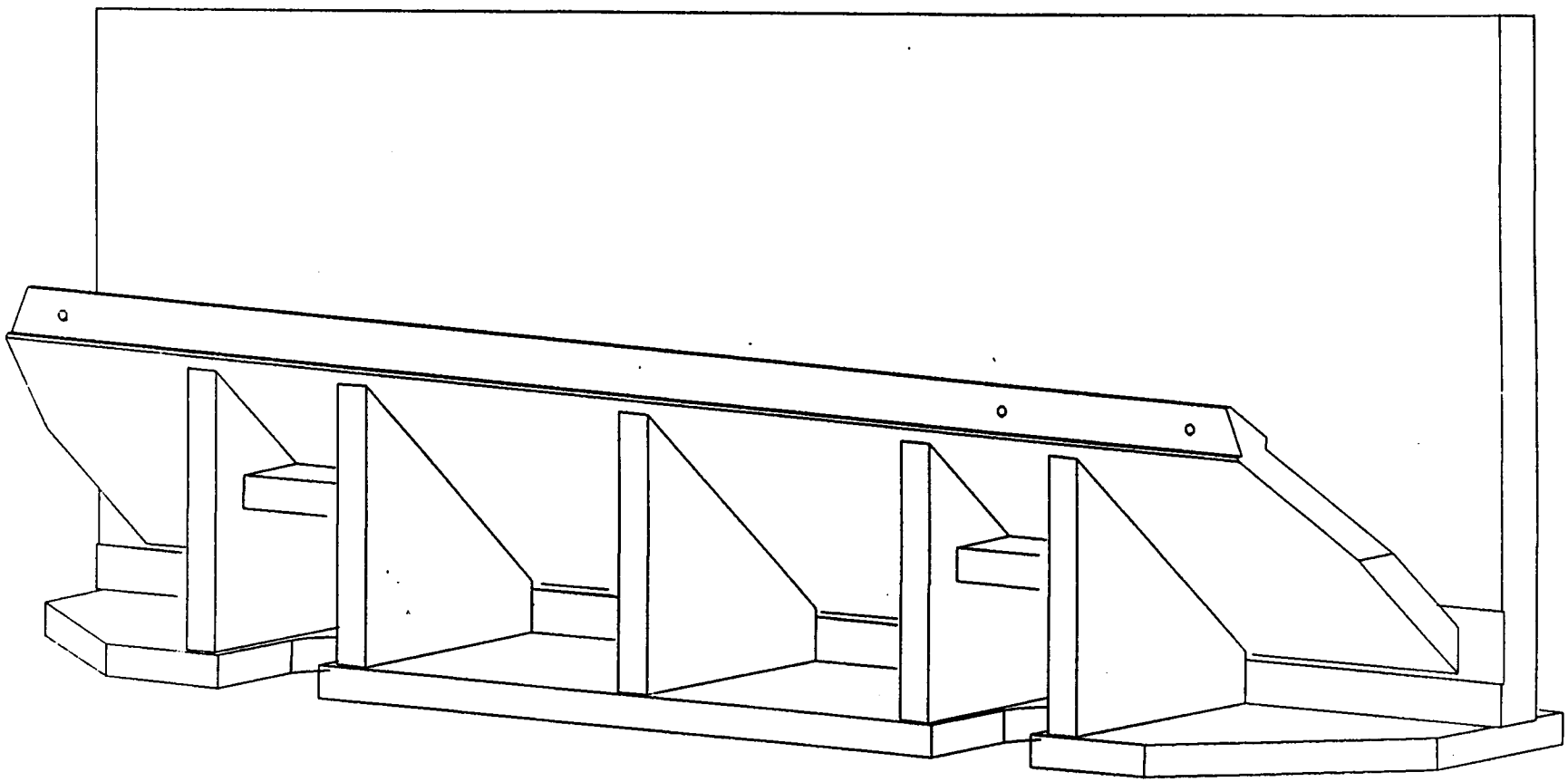


JMB-14
4/29/93

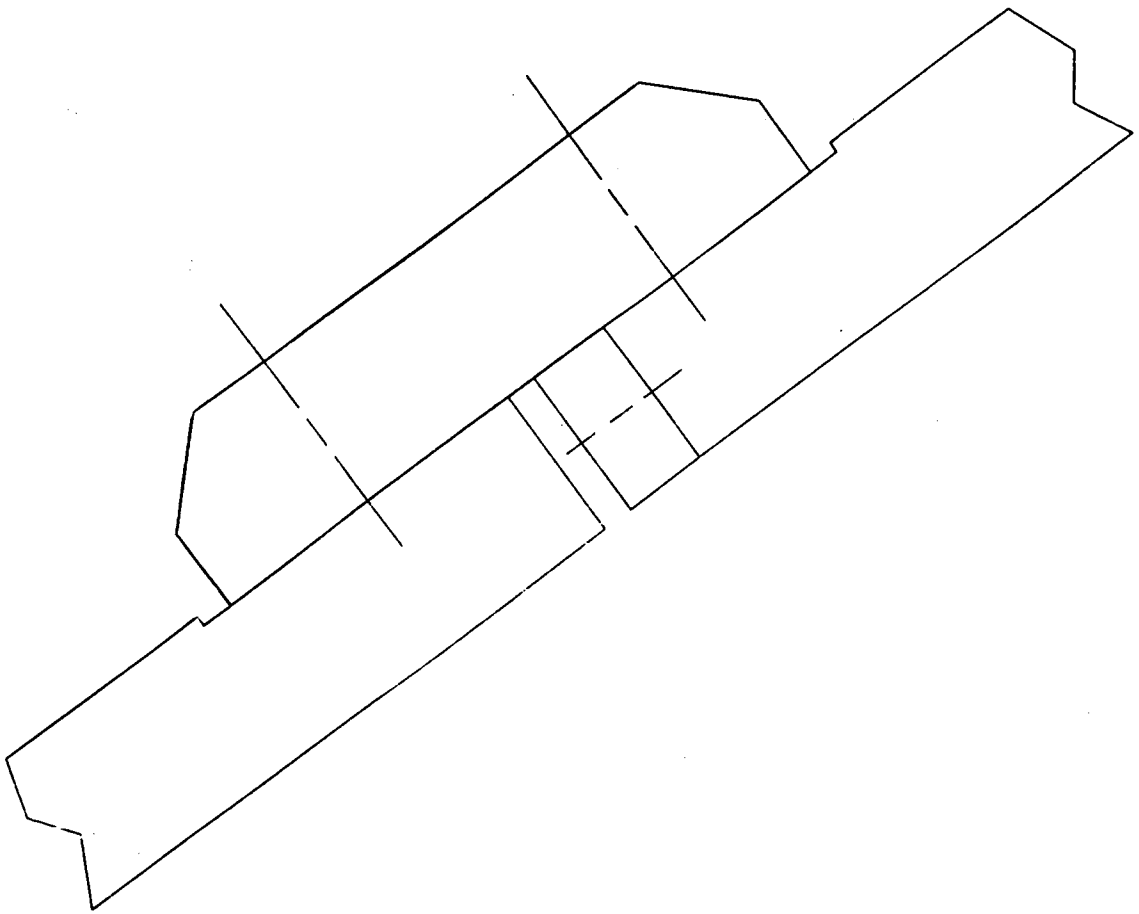

Y
Z
X

Bottom lampshade connection




Y
Z
X

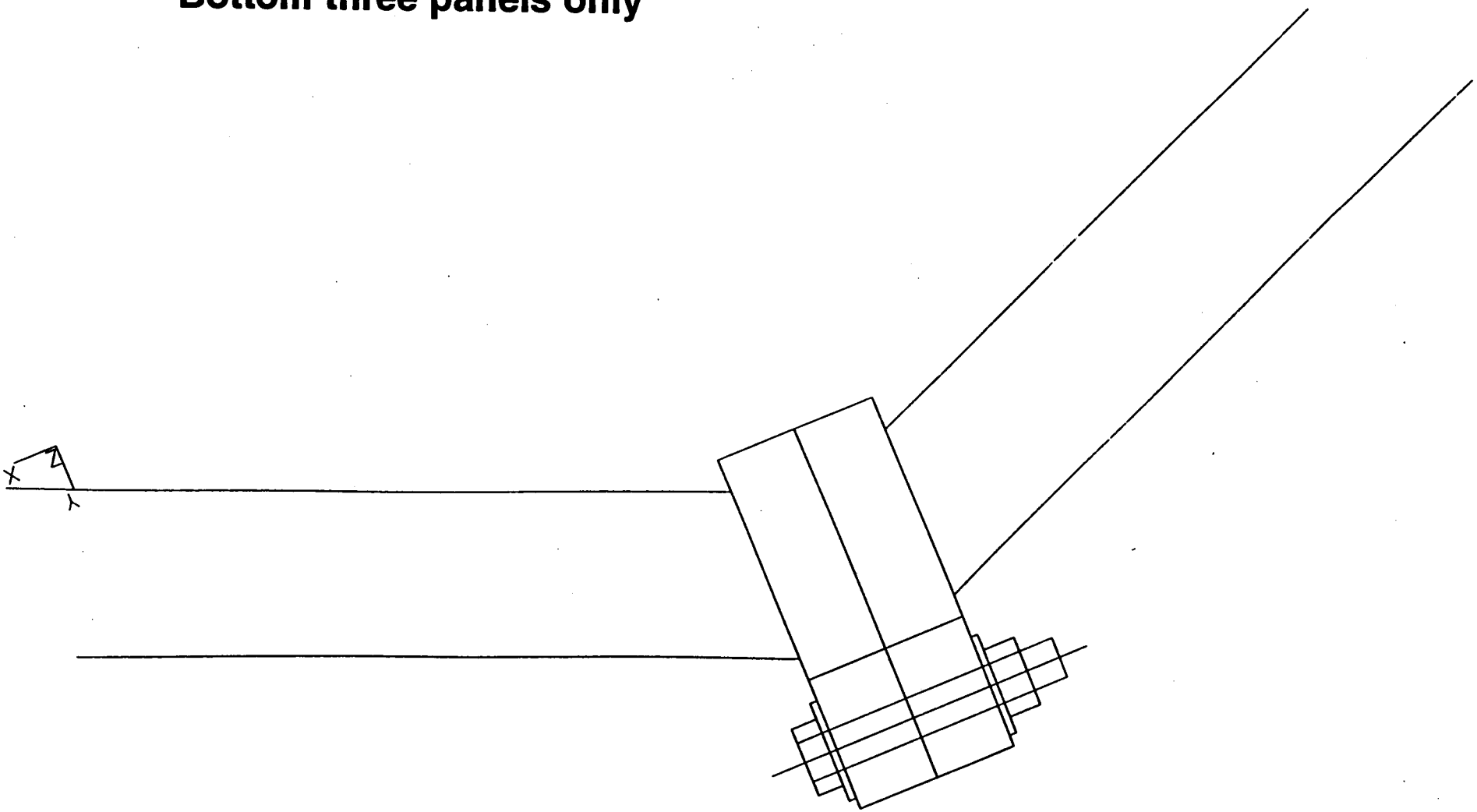
Lampshade-teacup connection



JMB
7/29/93

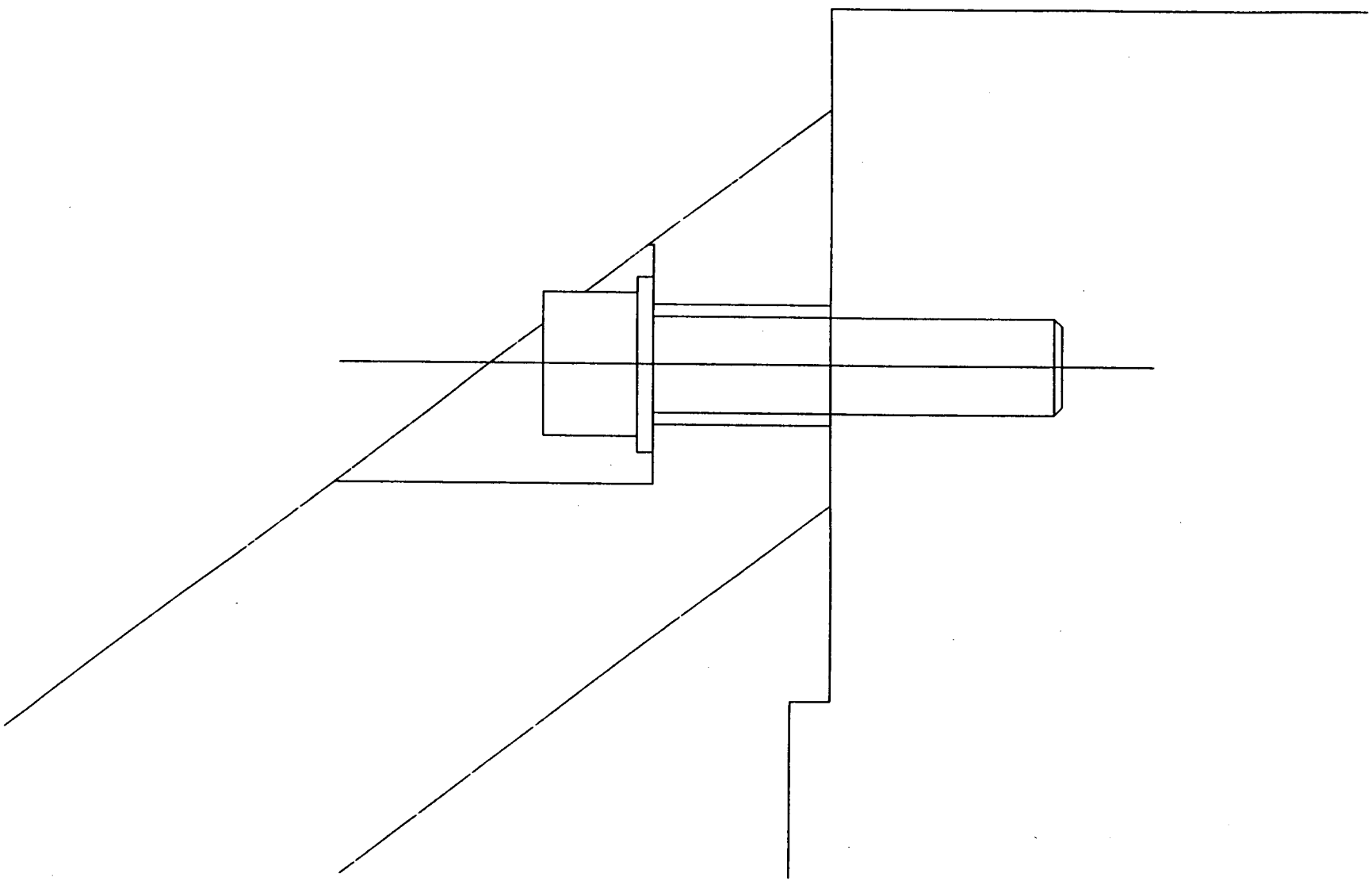
Lampshade-lampshade connection

Bottom three panels only



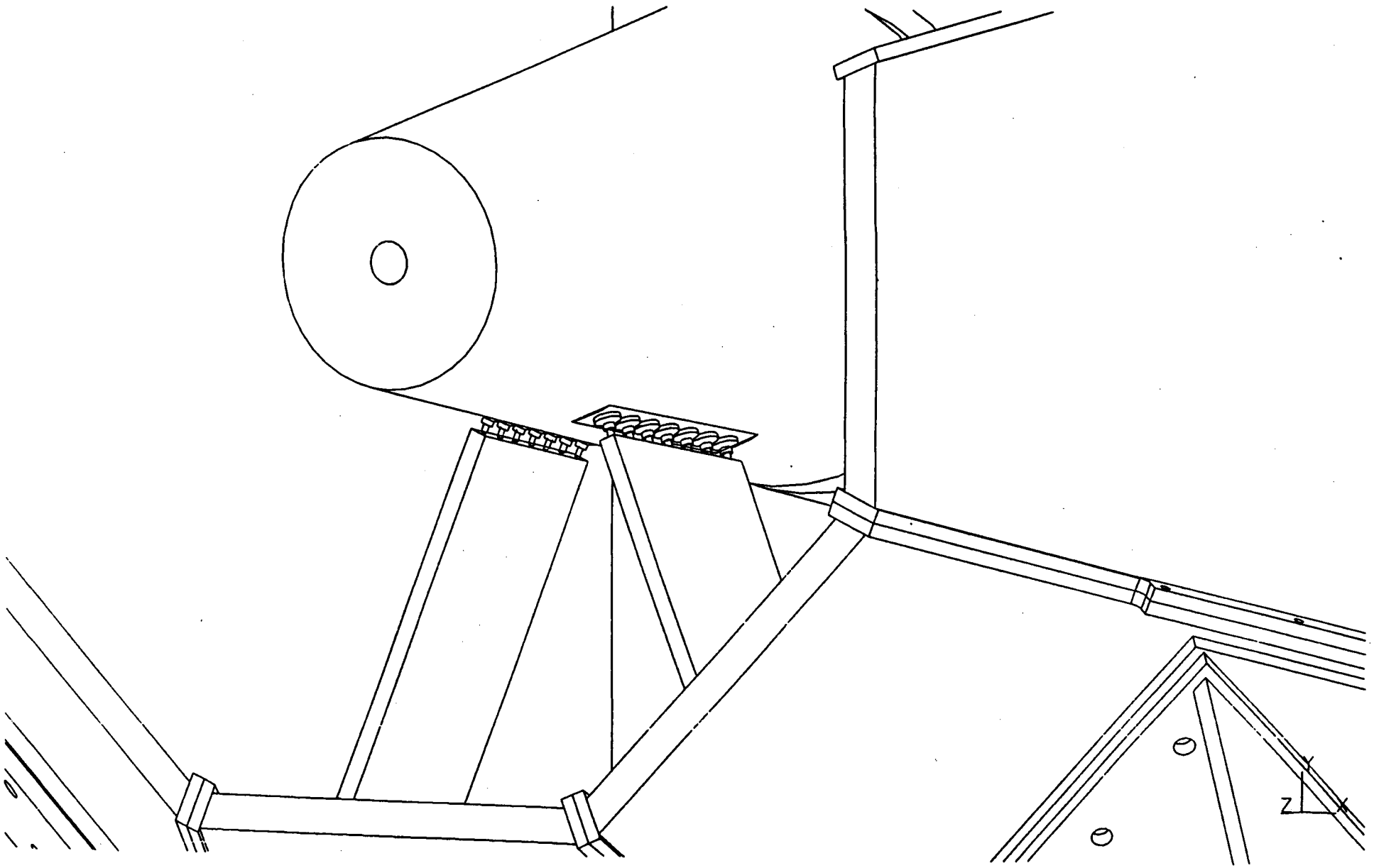
JMB
7/29/93

Lampshade-backplate connection



Stabilizer fin design

- 50mm thick 310 stainless steel
- 0.6 m long in Z direction
- Only two fins required for stabilization
- Both fins removable and adjustable
- Piston is self supporting without the fins
- Only remove top lampshade plate to allow crane access for coil and fin installation


Z
Y
X

Fin/piston connection

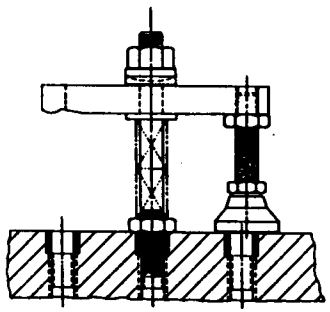
- Jig feet attached to fins support the piston end
- Jig feet accommodate 6 degrees of freedom for tolerance stackups, total of 140,000 lb load carrying capacity

STUD LEVELING FEET

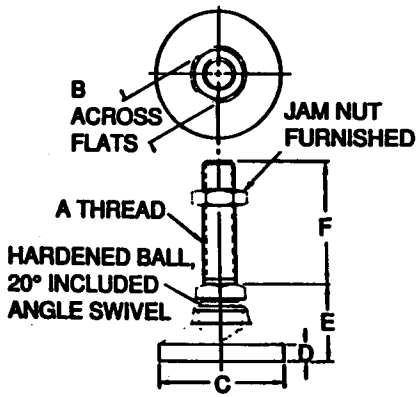
STEEL: 12L14, CARBURIZED-HARDENED (BODY ONLY), ZINC PLATED YELLOW CHROMATE
STAINLESS STEEL: 300 SERIES

NEW LARGE SIZE & METRICS!

Heavy-duty leveling foot with large-diameter pad and integral stud. Stud and ball are one solid piece. Available in steel, steel with a Delrin pad, or stainless steel.



Can also be used as a clamp rest for Tapped-Heel Clamp Straps.



USA

PART NO. STEEL PAD & BODY	PART NO. DELRIN® PAD STEEL BODY	PART NO. STAINLESS PAD & BODY	A	B	C DIA	D	E	F	LOAD RATING (LBS.)* STL & SS	LOAD RATING (LBS.)* DELRIN®
CL-6-SLF	CL-6-SLFN	CL-6-SLF-S	3/8-16	9/16	1-1/4	3/16	7/8	2	2,300	300
CL-8-SLF	CL-8-SLFN	CL-8-SLF-S	1/2-13	3/4	1-7/8	1/4	1-1/8		4,200	700
CL-10-SLF	CL-10-SLFN	CL-10-SLF-S	5/8-11	7/8	2-1/2	5/16	1-1/4		6,600	1,200
CL-12-SLF	CL-12-SLFN	CL-12-SLF-S	3/4-10	1-1/8	3	1/2	1-1/2		10,000	1,800
CL-16-SLF			1-8	1-3/8	4	13/32	1-7/8	4-1/4	18,000	

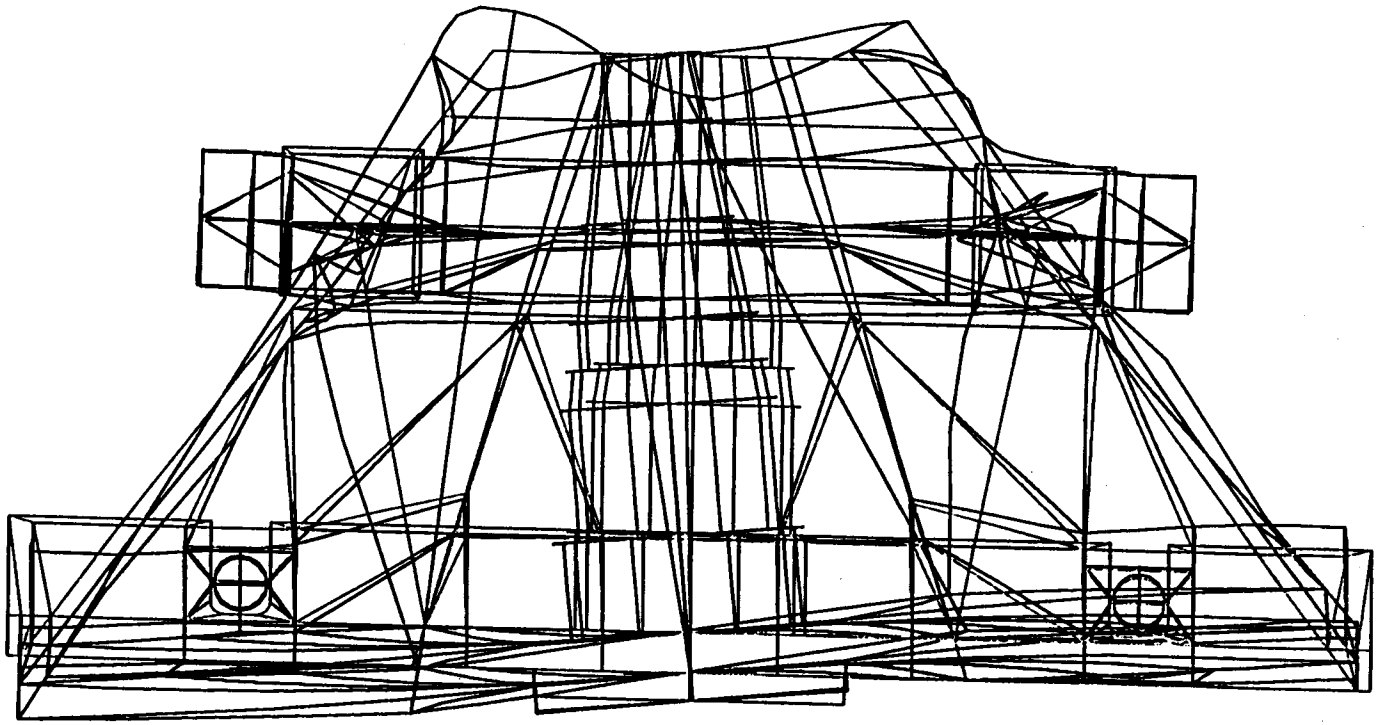
METRIC

CLM-10-SLF			M10	17mm	1-1/4	3/16	7/8	2	2,600	
CLM-12-SLF			M12	19mm	1-7/8	1/4	1-1/8		3,800	
CLM-16-SLF			M16	24mm	2-1/2	5/16	1-1/4		7,200	
CLM-20-SLF			M20	30mm	3	1/2	1-1/2		11,000	

*Safe static load with stud securely mounted in a plate at least one-stud-diameter thick, at maximum stud extension (2:1 safety factor). Leveling Feet are rated with the same-length stud as on Stud Leveling Feet. Load capacity will drop significantly with longer studs.

Muon magnet finite element analysis

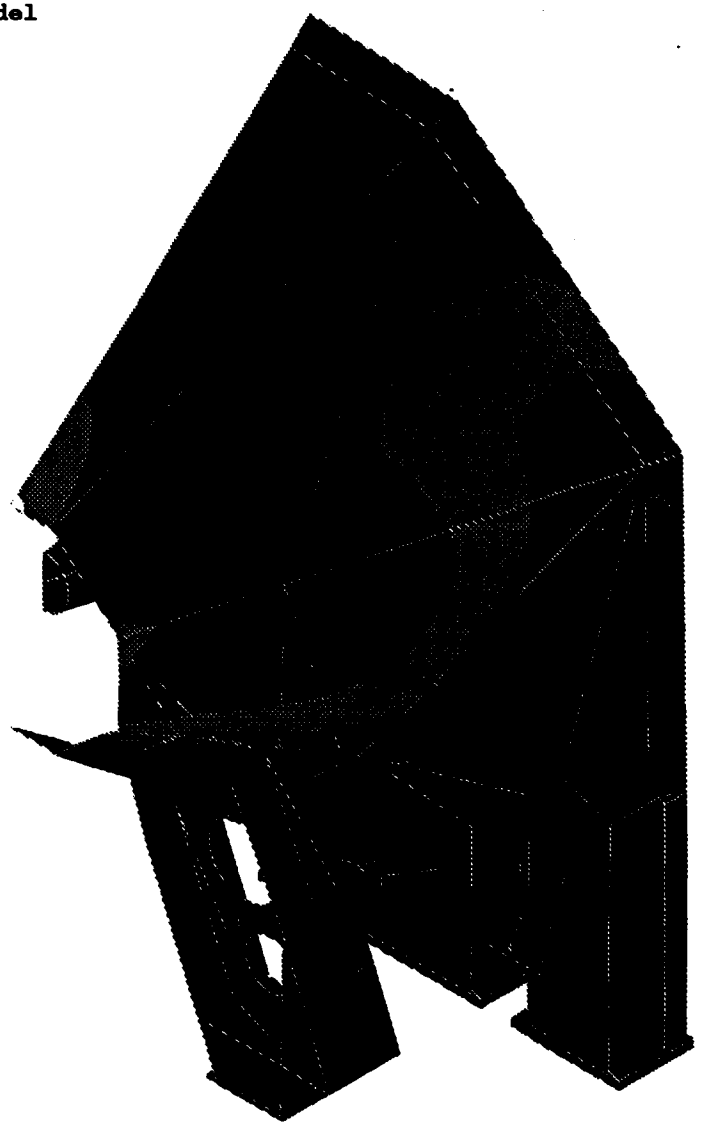
Analyses by Marcus Libkind
Software: Rasna/ Mechanica/Applied Structures



Earthquake loads: Muon Magnet Assembly

- Design total weight = 500 tons
- Pullout loads are present only on the front legs
- Maximum vertical acceleration = .35g (from the PDR)
- Maximum horizontal acceleration = .52g (from the PDR)
- Maximum upward force on leg to base plate bolts = 133 tons
  - Factor of safety of leg to base bolts = 3.0 (Yld. M30, 8.8 bolts)
  - Factor of safety of leg to panel bolts = 2.8 (Yld. M30, 8.8 bolts)
  - Base plate concrete studs, percent of allowable load = 80 (1.25" Dia. studs, 12" depth in concrete)

Displacement Mag
Max +1.1480E+00
Min +0.0000E+00
Deformed Original Model
Max Disp +1.1480E+00
Scale 4.4446E+02
Load: kahn



millimeters

+1.020E+00

+8.929E-01

+7.653E-01

+6.378E-01

+5.102E-01

+3.827E-01

+2.551E-01

+1.276E-01

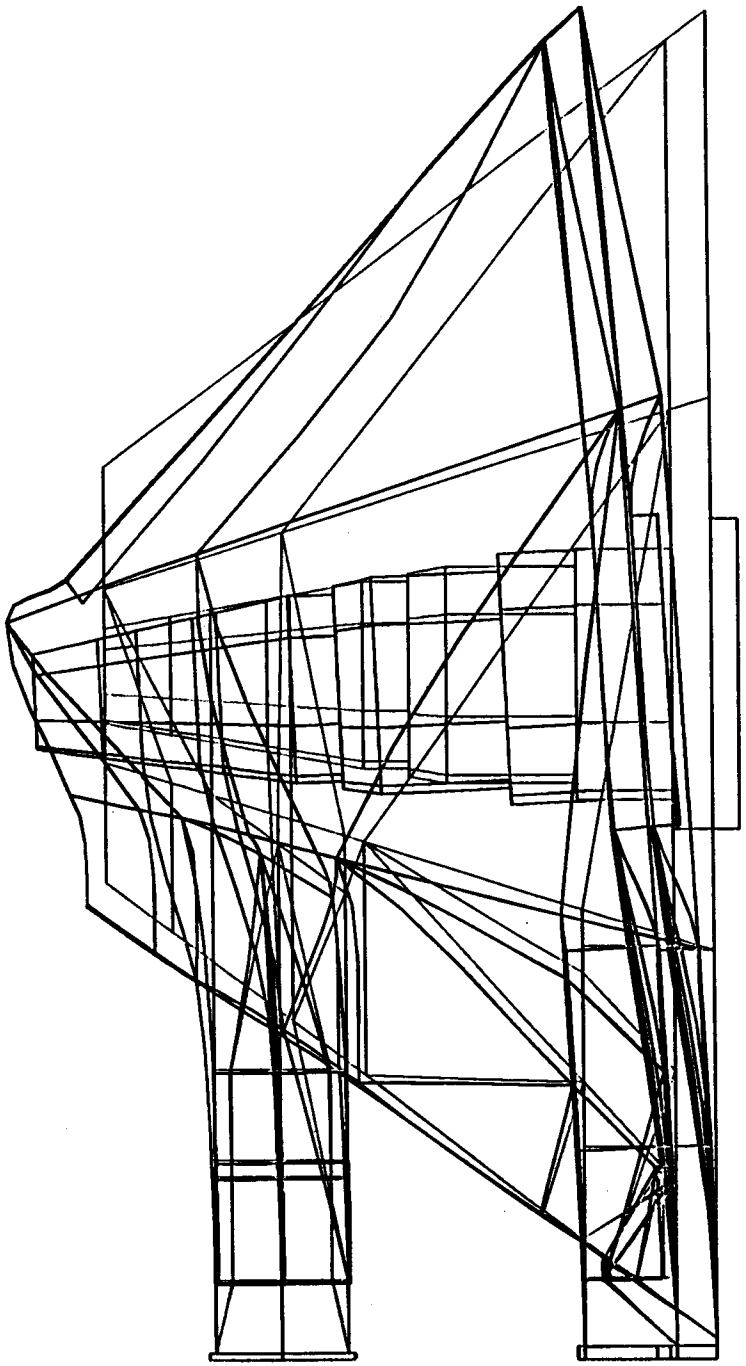
"disp_mag" - ds_1_2gg_gm1 - gm1

Summary of Displacements for MM

	Gravity Only	Magnetic Only	Gravity plus Magnetic
Magnitude			
Lower panels	.001-.1	0-.03	.001-.13
Y-Axis			
Front of piston	-.14	+.11	-.03
Top panel (front)	-.49	-.42	-.91
Z-Axis			
Piston	-.1	+1.2	+1.1
Top of backplate	-.38	-.28	-.66

Units are millimeters

Displacement Mag
Deformed Original Model
Max Disp +1.1049E-01
Scale 9.2738E+03
Mode 1, +1.1940E+01 Hz.

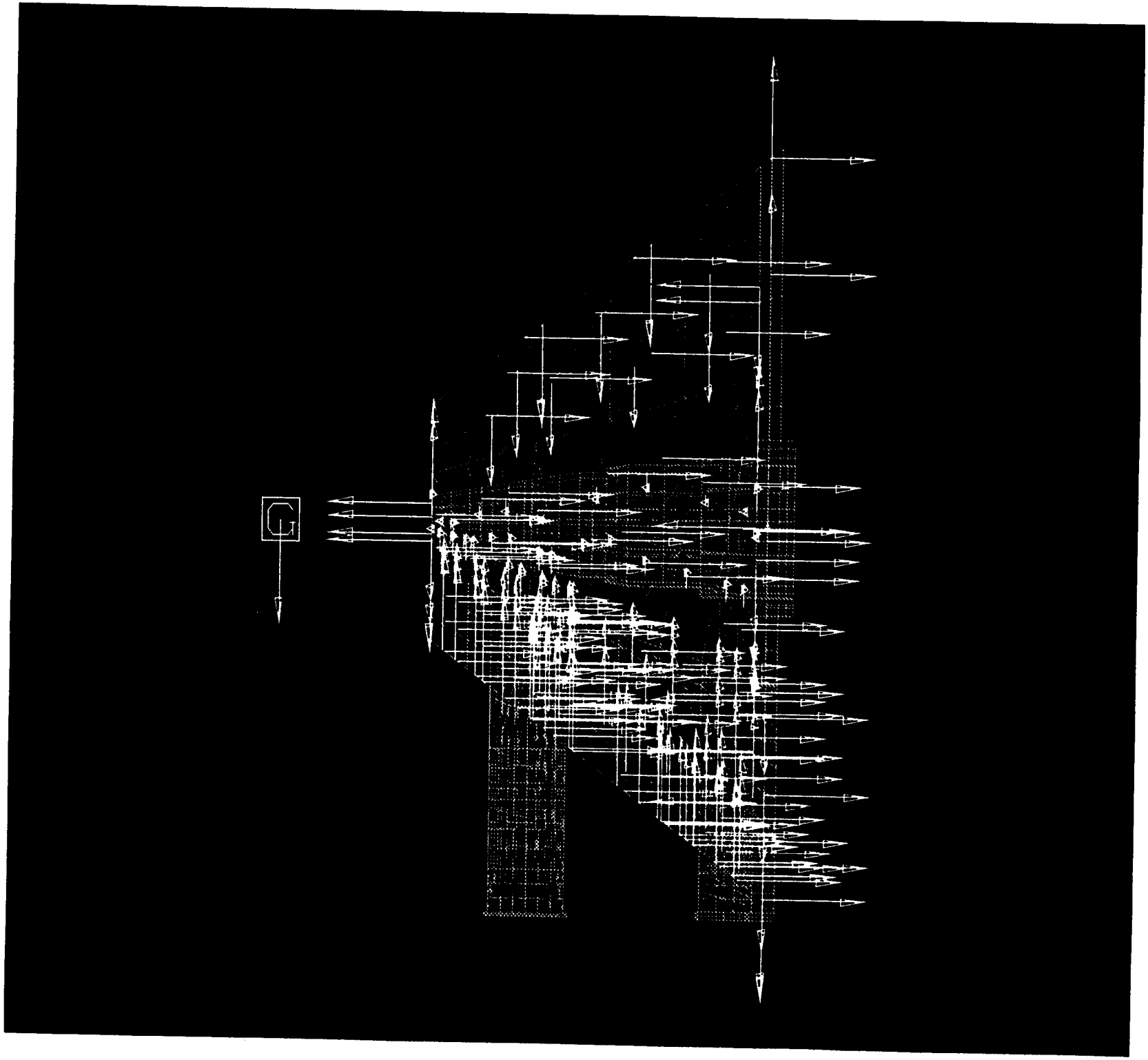


Y
Z
X

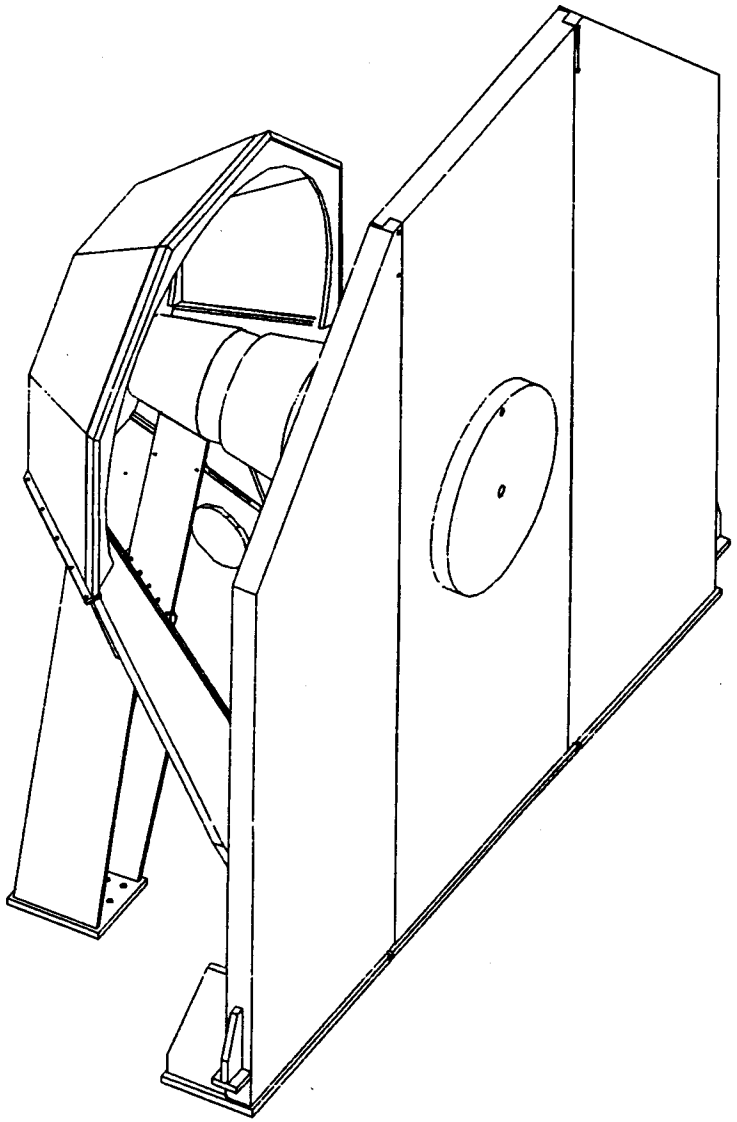
"model" - ds_1_2b_mode3 - mode3

Modal Analysis of MM

- First mode 11.9 Hz
- Second mode 22.5 Hz
- Third mode 24.9 Hz


G

Muon magnet July concept



JMB
7/28/93

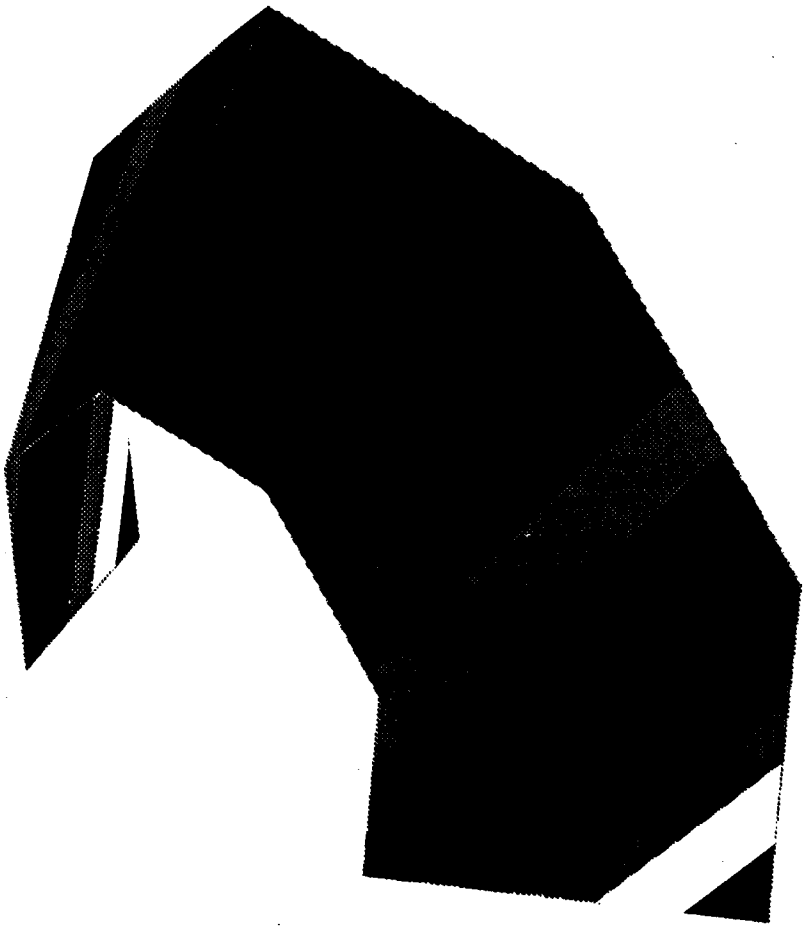
Teacup lifting analysis

Issue: rigged teacup will resonate/deflect during lift

- five sided arc is a massive (12 ton)
- .. and first 3 modes are under 15 hz
- ... and static horizontal deflection is 10 mm on each side

Solution: add two permanent "arches" to leading and trailing edges. Deflection drops by factor of 10.

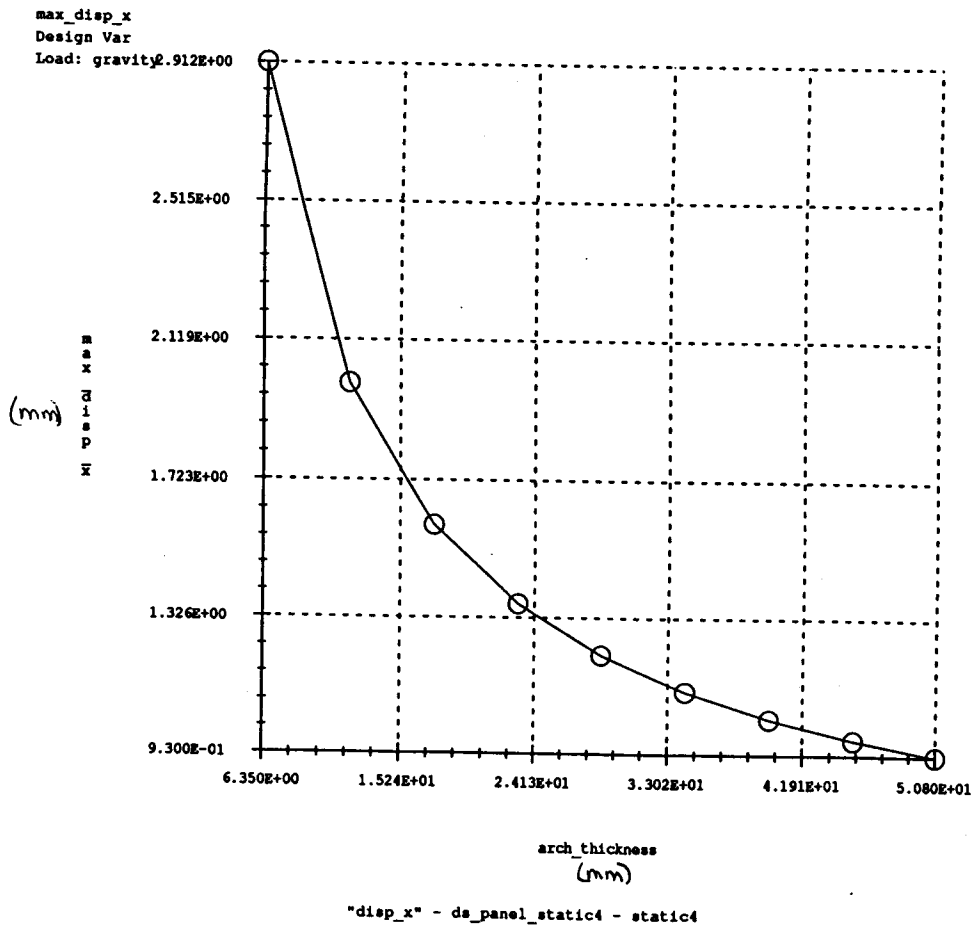
Displacement Mag
Max +1.2917E+01
Min +0.0000E+00
Deformed Original Model
Max Disp +1.2917E+01
Scale 4.5695E+01
Load: gravity



+1.148E+01
+1.005E+01
+8.611E+00
+7.176E+00
+5.741E+00
+4.306E+00
+2.870E+00
+1.435E+00

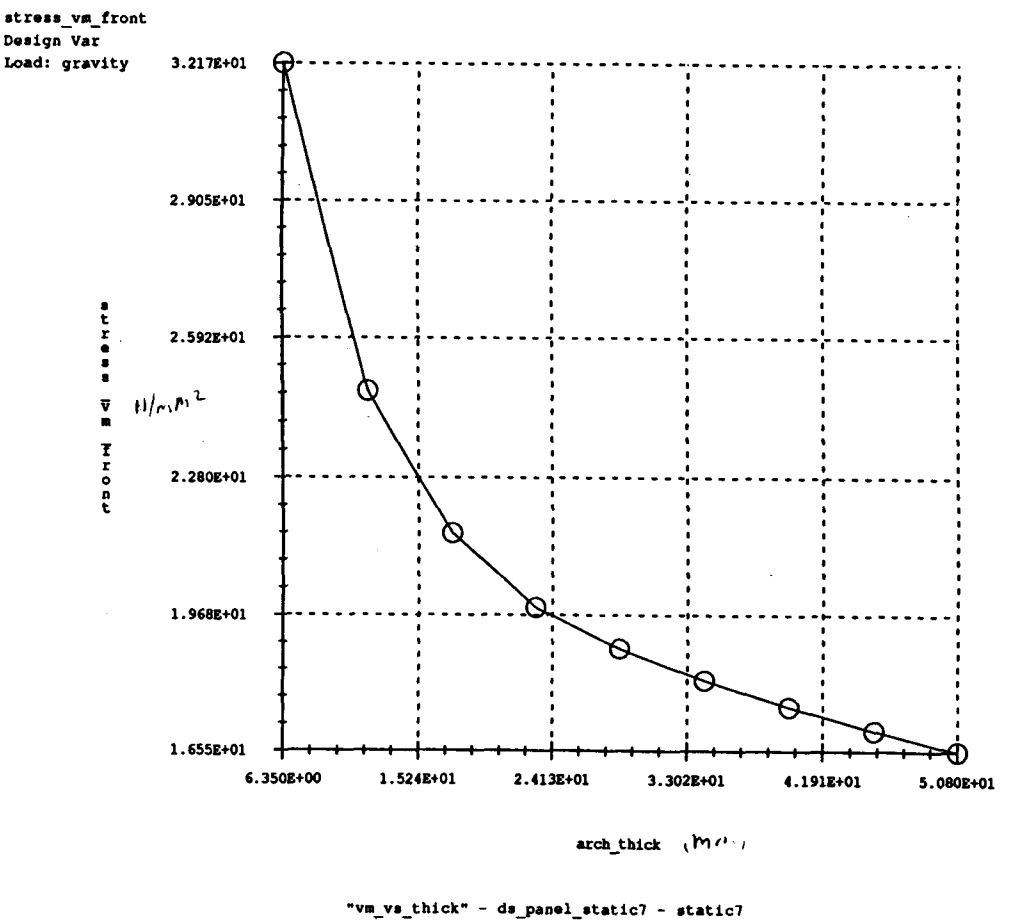
"disp_mag" - da_panel_static2 - static2

Teacup deflection vs arch thickness



JMB
7/29/93

Arch stress vs arch thickness



JMB
7/29/93

Shoreham facility option

- Consulting with Long Island Lighting Company (LILCO) to contract use of their dock facility at the Shoreham nuclear power plant

- Talking with rigger who has experience shipping to the Shoreham facility (Lockwood Brothers, Virginia)

- Close proximity to BNL makes this an ideal option

- Approximate shipping time of February is good because ground is likely to be frozen.

JMB
7/28/93

Accountability of Russian procurements

- LLNL fabrication specification will be part of purchase order
- Specific milestone hold points on the construction schedule included in purchase order
- Construction progress payments are tied directly to completion of each milestone
- LLNL will provide coordinator/inspector/quality assurance personnel to perform these services
- Approximately 12 man months of construction support will be required, including travel
- Approximately 24 man trips to Russia will be made by various specialists over a period of about one year.

Procurement Plan

- Five categories of construction activities:

1) Russia Hardware

2) U.S. Hardware

3) U.S. labor in the U.S.

4) U.S. labor in Russia

5) Russian labor in Russia

Procurement Plan: Russian Hardware

Prime Contractor: Petersburg Nuclear Physics Institute (PNPI)

Russian Project Management Office: D. V. Efremov Scientific Research Institute of Electrophysical Apparatus

Muon piston magnet core (1)
Muon detector back plates (3)
Muon lampshade plates (8)
Muon piston support fins (2)
Muon system support legs (2)
Central detector return yokes (2)
Central detector pole rings (2)
Central detector pole keys (4)
Central detector pole pieces (2)
Central detector pole cores (2)
Central detector outrigger weldments (4)

Procurement Plan: U.S. Hardware

Some items should be procured domestically, for various reasons:

Item	Reason
Alloy steel cap screws, nuts, and washers	Safety risk
Wide flange beams and structural angles	English units
Concrete anchor studs	Safety risk
Weld studs	English units
Muon Doors and tracks	Local testing
Door operating cylinders	Spare parts
Door hydraulic hand pumps	Spare parts
Door guide rollers	Quality
Door belleville washers	Quality
Door pillow blocks	Quality/Safety
Transporter rollers (300 ton)	Safety risk
Lifting jacks	Safety risk
Other rigging equipment (shackles, wire rope, pulley blocks etc)	Safety risk

U.S. labor in the U.S.

- Fabricate muon doors, tracks, test fixture (US shop)
- Operate muon doors on test stand (LLNL)
- Fabricate Central magnet support frame (US shop)
- Prepare PHENIX high bay for magnet installation (BNL/LLNL)
- Off load major components from trans ocean carrier (Contractor)
- Ship components by barge from port of entry to Shoreham Nuclear Facility (Contractor)
- Off load major components at Shoreham (Contractor)
- Haul major components to BNL (Contractor)
- Erect central magnet and Muon Magnet (Contractor)
- Perform final alignment of magnet (LLNL/BNL/Contractor)

U.S. labor in Russia

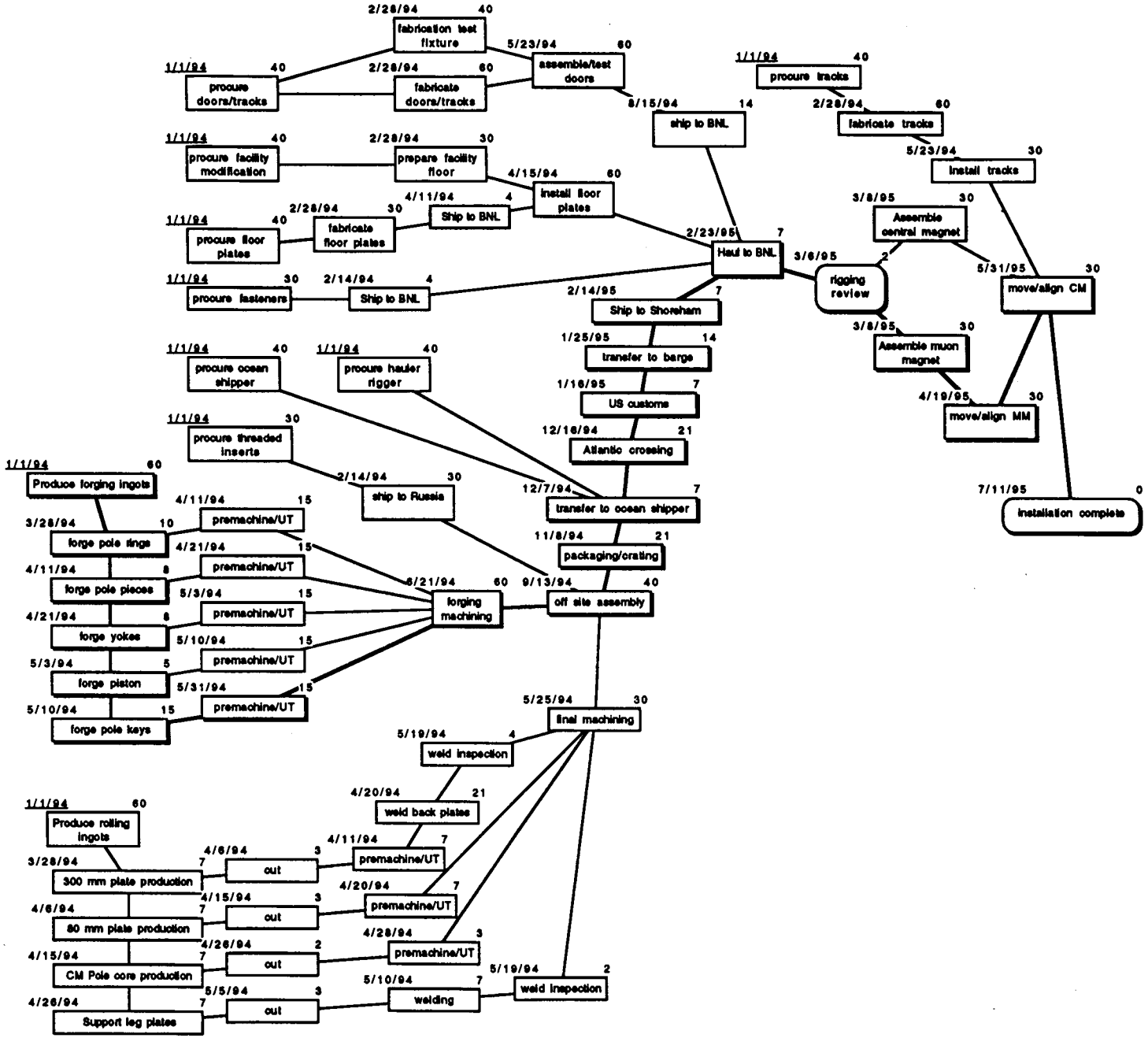
- Witness steel production chemical analysis
- Witness mechanical, magnetic, and chemical coupon testing
- Audit welding QA records
- Witness ultrasonic inspection
- Perform dimensional inspection on parts
- Perform weld inspection
- Witness assembly
- Perform dimensional inspection on assembly
- Witness packaging for shipment

Russian labor in Russia

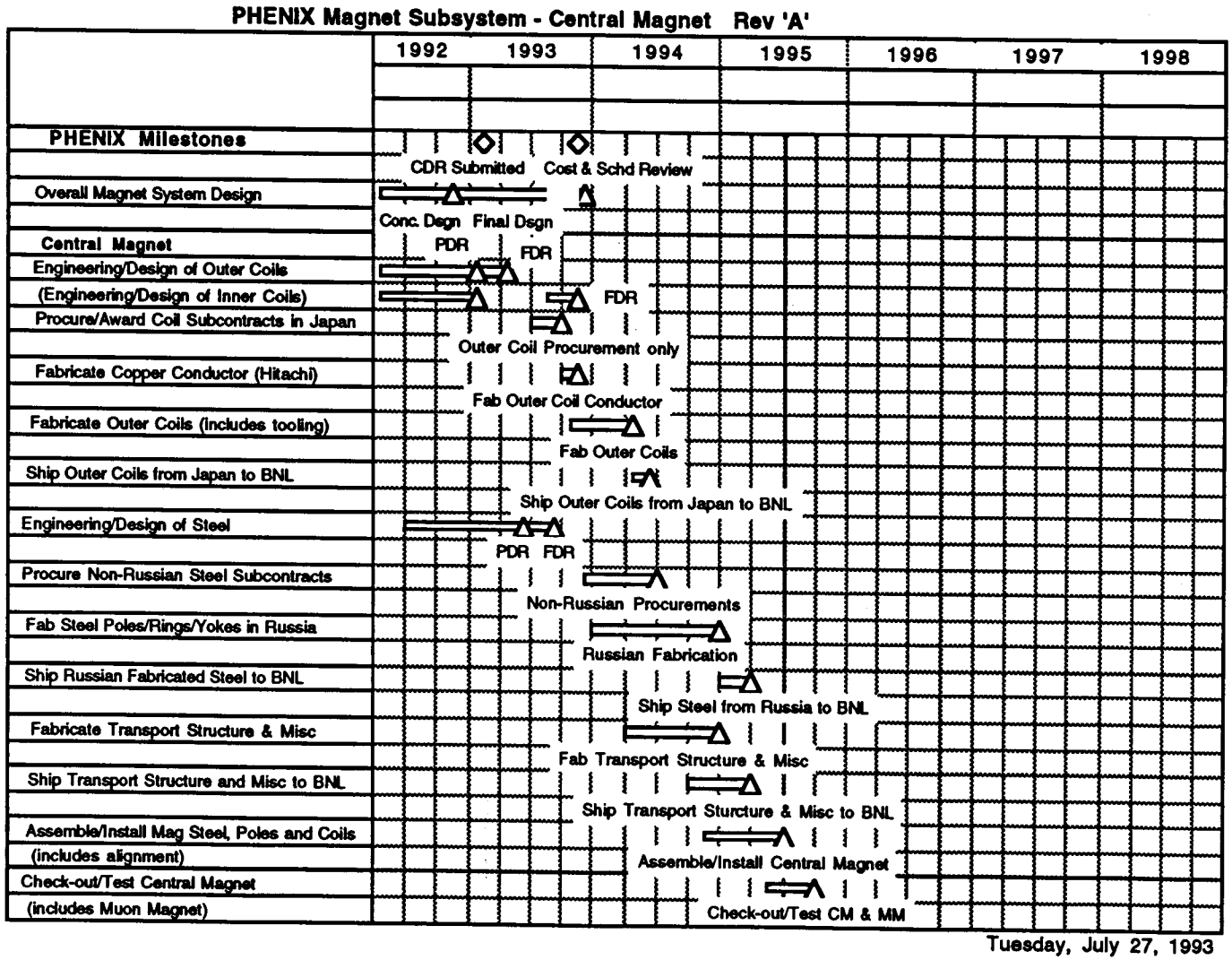
Items included on steel purchase order:

- **Steel production**
- **Analysis and material testing**
- **Preparation of test reports (CMTR's, UT, etc)**
- **Maintenance of PHENIX fabrication quality assurance records**
- **Fabrication and machining**
- **In house ultrasonic testing, dimensional and weld**
- **Assembly and off site rigging**
- **Packaging for shipment**
- **Transfer and loading to ocean carrier**

PHENIX Magnet Steel Schedule

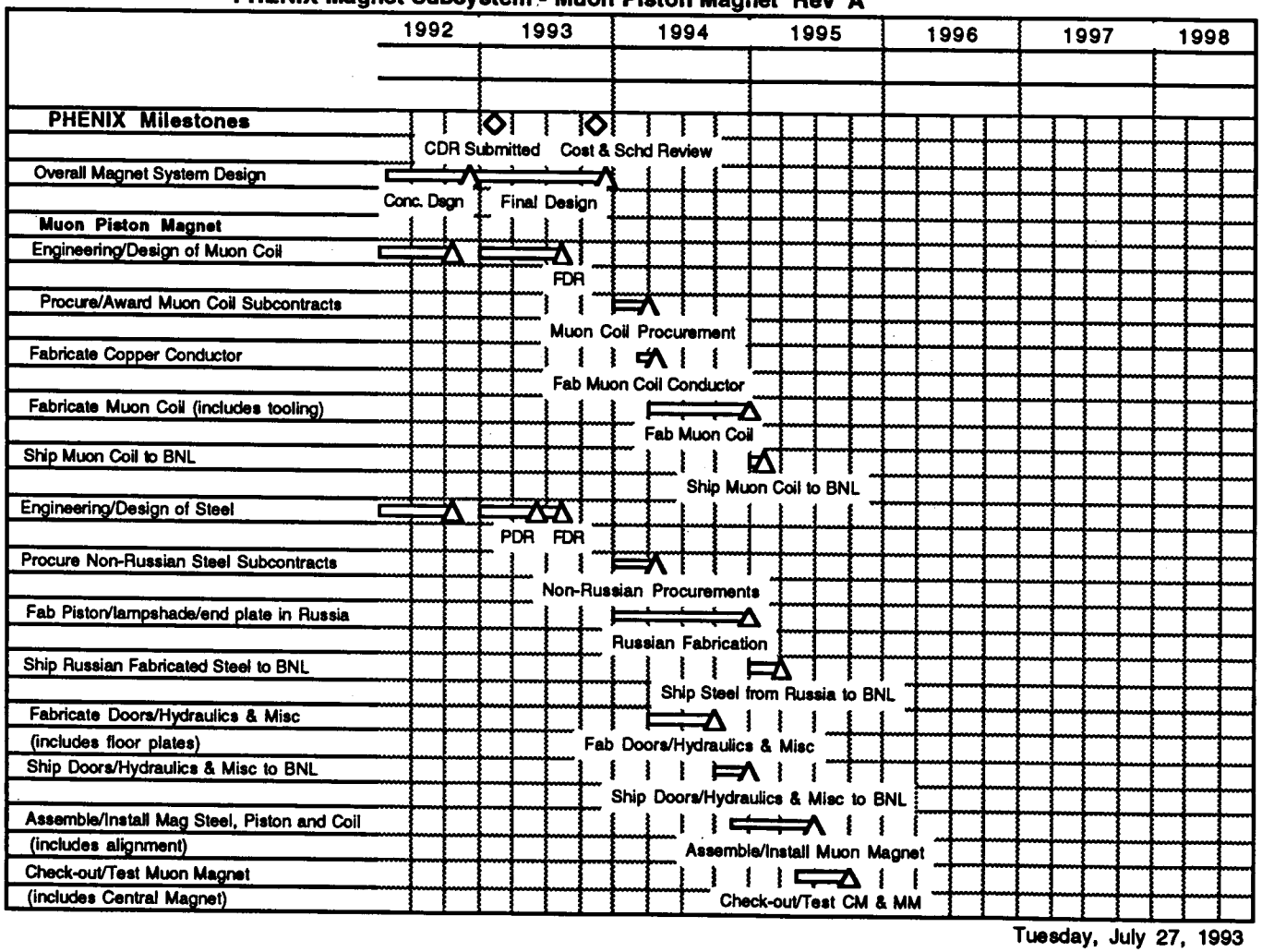


Central magnet schedule



JMB
7/28/93

Muon magnet schedule



JMB
7/28/93

Hazards analysis: central magnet

SYSTEM:PHENIX Magnet — **PROJECT ENGINEER: J. Bowers**

DATE: August 2-3, 1993 — **REVISION: 0**

SUBSYSTEM: Central Magnet Steel — **SHEET 1 of 1**

1		2						3
Component		Hazard						Preventative Action
				CLASS*				
No	Description	Mode	Effect	1	2	3	P**	
1	Structural tie down	Seismic	structural failure		2		L	Analysis, Factors of safety
2	Transport system	operation	personal injury		2		L	Procedures/qualified personel

*Hazard class:1-minor, 2-moderate, 3-major ** probability: L=low, M=Medium, H=high

JMB
7/28/93

Hazards analysis: muon magnet

SYSTEM:PHENIX Magnet — **PROJECT ENGINEER: J. Bowers**

DATE: August 2-3, 1993 — **REVISION: 0**

SUBSYSTEM: Muon Magnet Steel — **SHEET 1 of 1**

1		2						3
Component		Hazard						Preventative Action
				CLASS*				
No	Description	Mode	Effect	1	2	3	P**	
1	Structural tie down	Seismic	structural failure		2		L	Analysis, Factors of safety
2	Door	operation	personal injury		2		L	Procedures/qualified personel
3	Lampshade plates	removal	personal injury		2		L	Procedures/qualified personel
4	Internal space	person fall	personal injury		2		L	Procedures/equipment/qualified personnel

*Hazard class:1-minor, 2-moderate, 3-major ** probability: L=low, M=Medium, H=high

JMB
7/28/93

Typical spreadsheet bolt calculation

- **Connection between pole key and lower yoke**

Force distribution on a linear bolt pattern

g's	0.52	
weight	200000	lb
cg height	232	inches
moment	24128000	in-lb

	Bolt 1	Bolt 2	Bolt 3	Bolt 4	Bolt 5	Bolt 6	Bolt 7	Bolt 8	
distance from centroid	61.02	57.09	53.15	49.21	13.78	9.84	5.91	1.97	inches
squares	3723.93	3258.93	2824.92	2421.62	189.89	96.88	34.88	3.88	
Force on bolt	117276	109709	102143	94572	26482	18916	11350.12	3784.014	total forces 484233 lbs

sum of squares 12554.93

Bolt size	Minor Diam	Area(sq mm	Area(sq in)	Stress (psi)
M12	9.93	77.44	0.12	977011
M16	13.93	152.40	0.24	496473
M20	17.93	252.49	0.39	299666
M24	21.26	355.01	0.55	213123
M30	27.92	612.22	0.95	123585
M36	33.26	868.86	1.35	87082
M48	45.25	1608.18	2.49	47048
M60	57.91	2633.81	4.08	28727

12.9 bolts ultimate	12.9 bolts yield	
170000	153000	
0.17	0.16	factor of safety
0.34	0.31	
0.57	0.51	
0.80	0.72	
1.38	1.24	
1.95	1.76	
3.61	3.25	
5.92	5.33	

JMB
7/29/93

E. Q. loads continued: Central Magnet Assembly

- **Factors of safety for bolted joints with earthquake loads, based on yield strength (must be => 1.0)**
  - **Lower yoke to key = 1.7 (M36, 12.9 bolts)**
  - **Lower key to ring = 1.6 (M36, 12.9 bolts)**

Magnetic Loads for CM

- Axial load pulling poles together is 172,700 lbs
- Radial load on return yoke is negligible

Summary of Displacements for CM

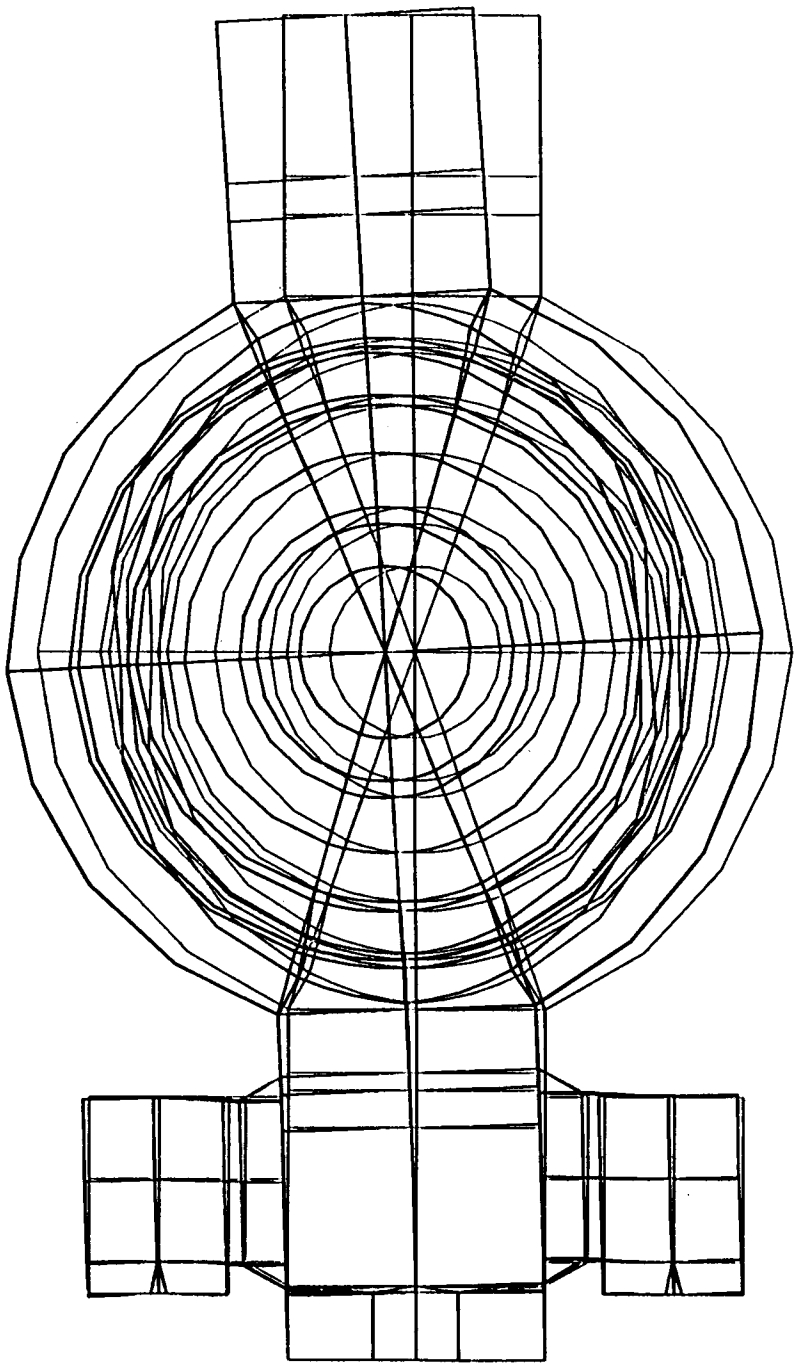
	Gravity Only	Magnetic Only	Gravity plus Magnetic
Magnitude (90° edge of eyebrow)	.11	.11	.22
Y-Axis (top of return yoke)	-.09	-.08	-.17
Z-Axis (90° edge of eyebrow)	-.08	-.12	-.20

Units are millimeters

Modal Analysis of CM

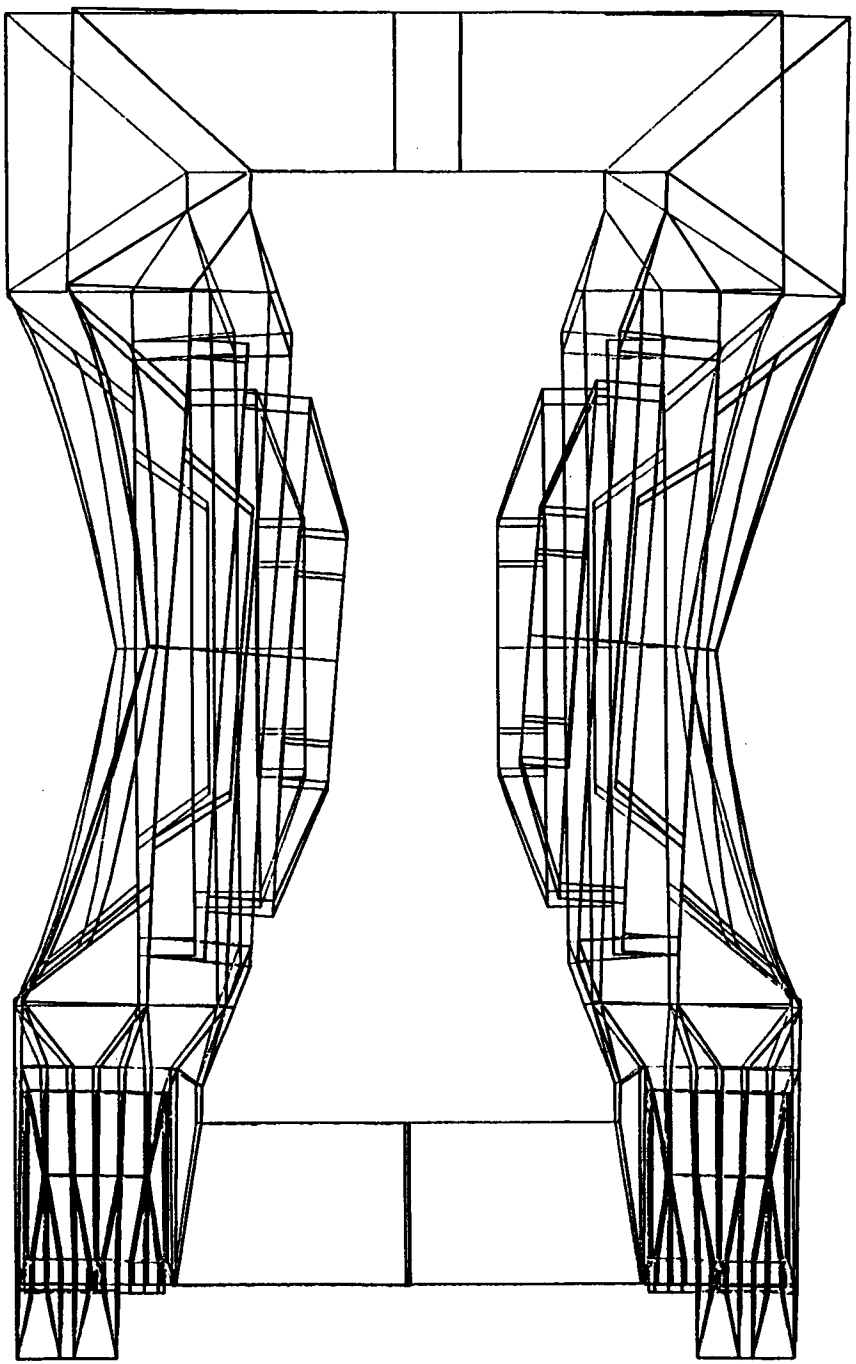
- First mode 11.7 Hz
- Second mode 13.7 Hz
- Third mode 25.2 Hz

Displacement Mag
Deformed Original Model
Max Disp +9.2138E-02
Scale 4.5371E+03
Mode 1, +1.1711E+01 Hz.

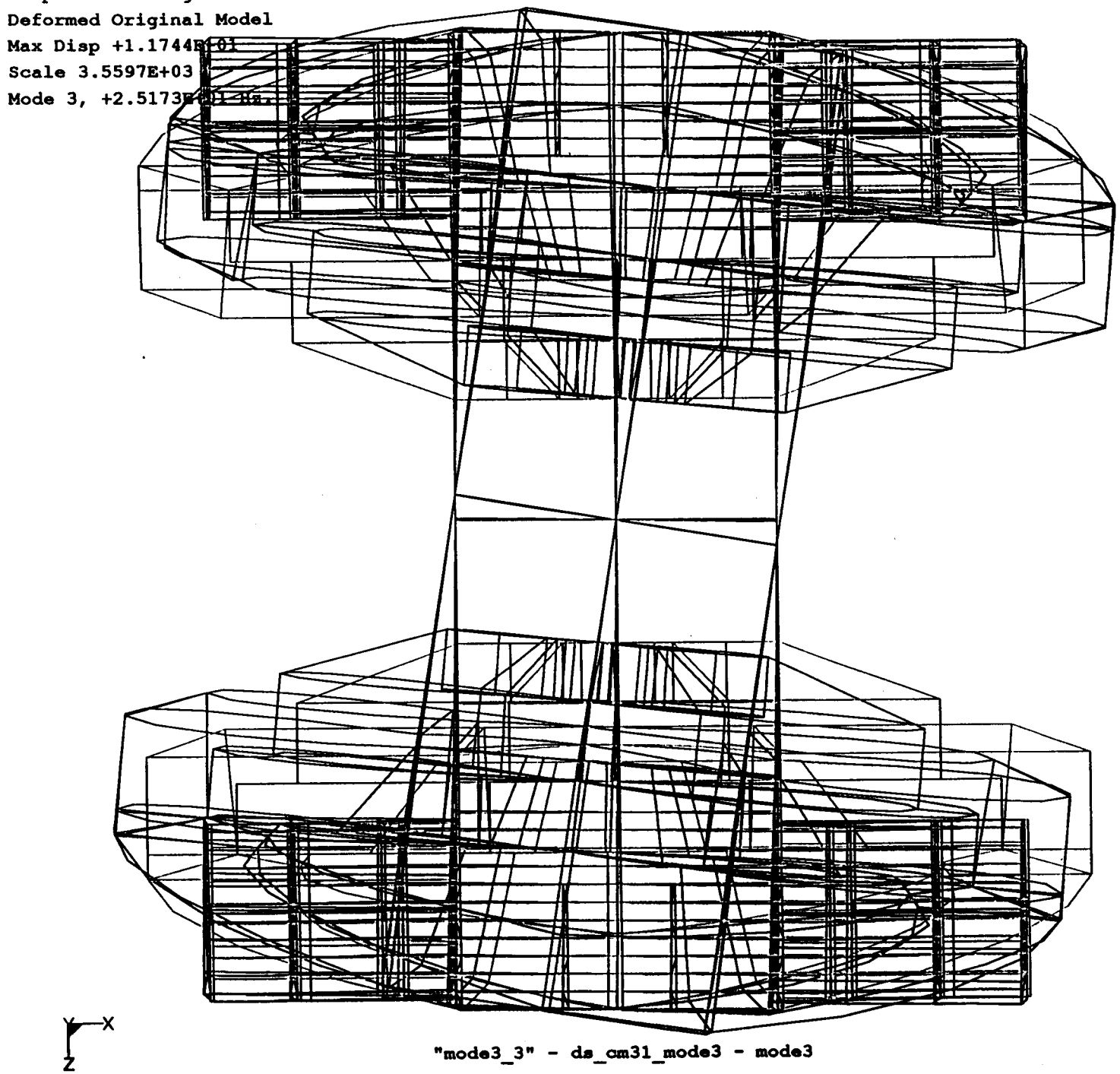


"mode3_1" - ds_cm31_mode3 - mode3

Displacement Mag
Deformed Original Model
Max Disp +8.6132E-02
Scale 4.8535E+03
Mode 2, +1.3686E+01 Hz.



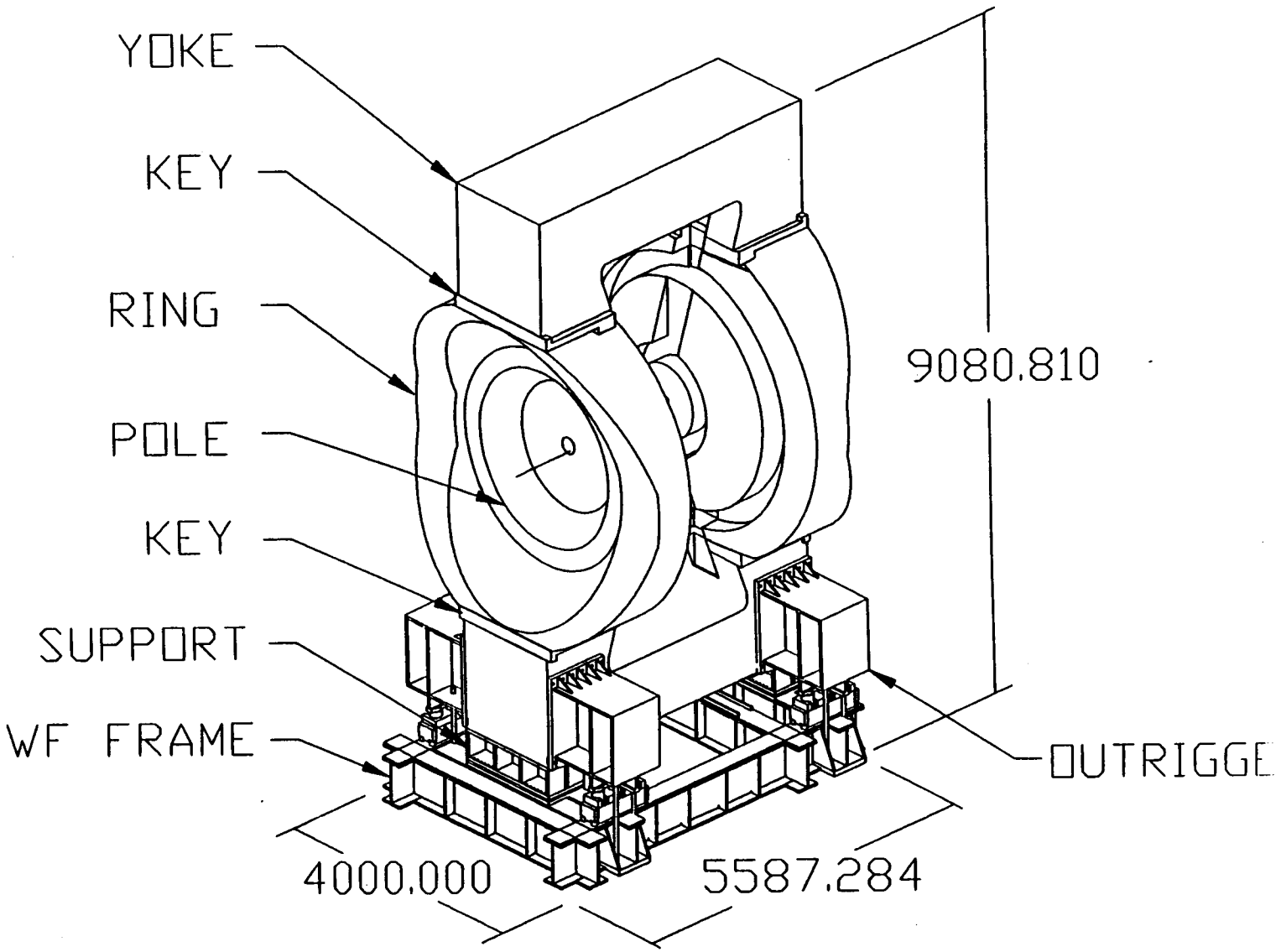
"mode3_2" - ds_cm31_mode3 - mode3


Displacement Mag
Deformed Original Model
Max Disp +1.1744E+01
Scale 3.5597E+03
Mode 3, +2.5173E+01 Hz.
Y
X
Z
"mode3_3" - ds_cm31_mode3 - mode3

Stress Analysis of Outrigger for CM

- Analysis shows that we need to be more sophisticated in our design of the outrigger in order to maintain our conservative approach.

Overall view of Central Magnet (June design)



JMB
7/29/93

Central Magnet component weights (June)

(Approximate)

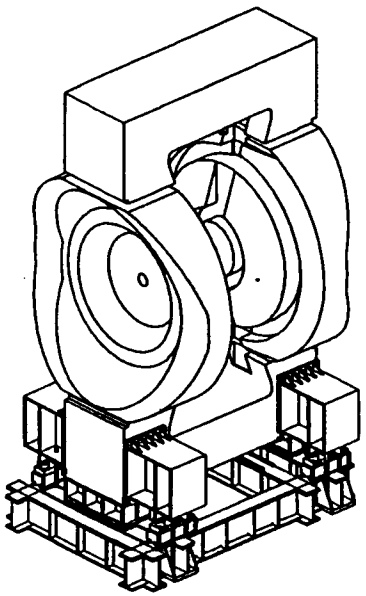
Item	Quantity	unit weight	total weight
Pole Ring	2	60	120
Pole Core	2	68	136
Pole Key	4	2	8
Return Yoke	2	87	174
Support Stand	2	2	4
		total weight:	442 tons
		transport design weight:	600 tons

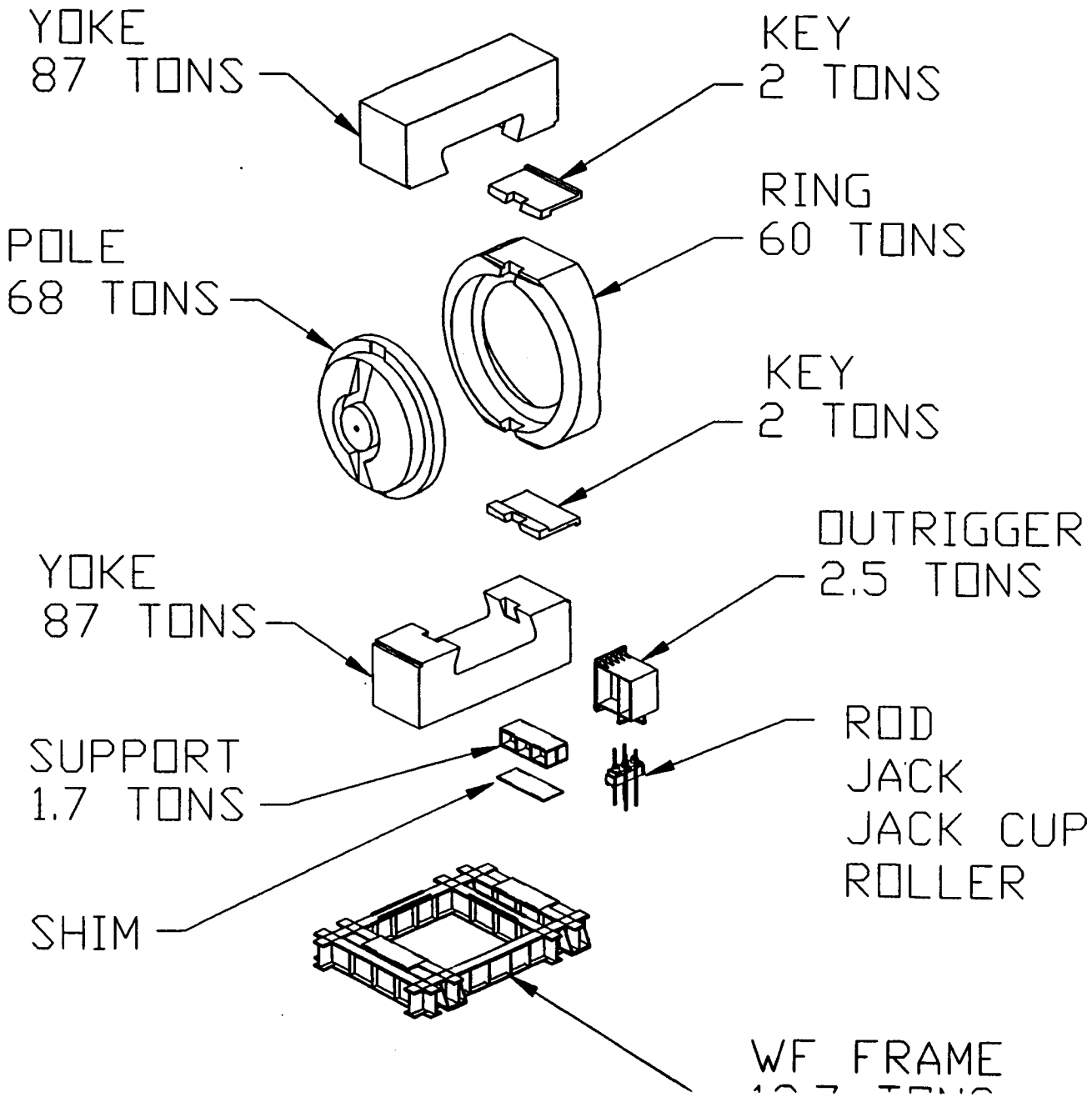
JMB
7/29/93

Primary design features (July Design)

- Transportable assembly, permanent outriggers
- Each pole made from three pieces to simplify fabrication
- Flux return yokes are smaller one piece forgings
- Designed for off site fit up
- Pole keys resist primary magnet loads

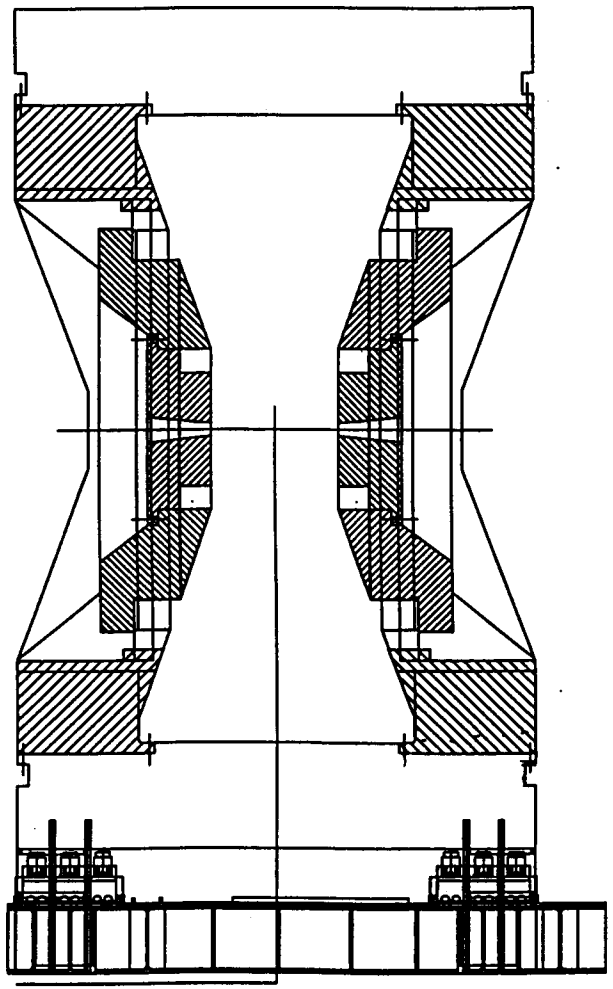
Central magnet exploded view





JMB-28
4/30/93

Central magnet cross section (July design)



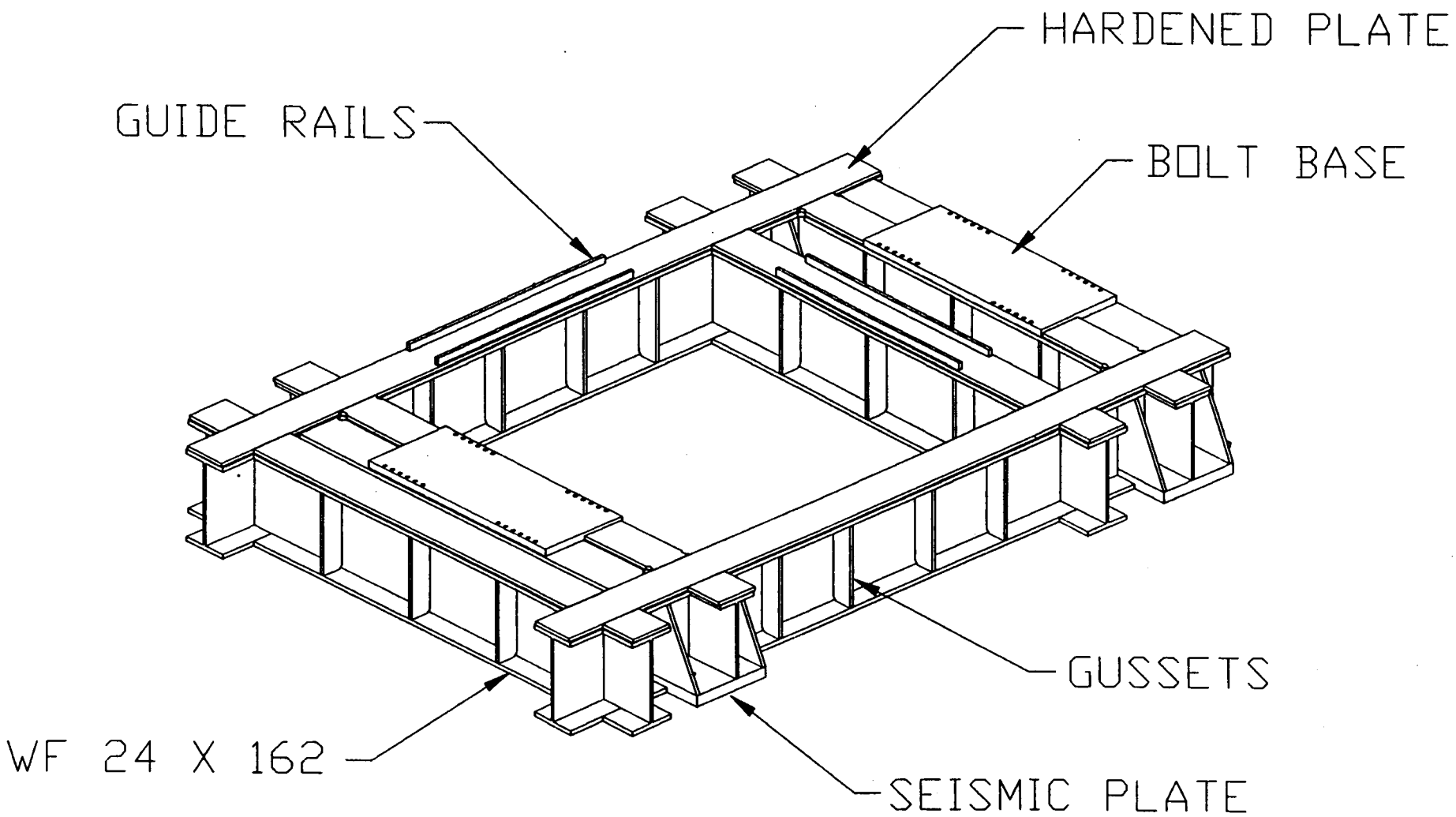
JMB
7/29/93

Effect of July design changes

- no change in assembled dimensions
- no significant change in total weight

Item	Quantity	unit weight	total weight
pole key	4	13	52 tons
yoke	2	65	130 tons
pole core	2	7	14 tons

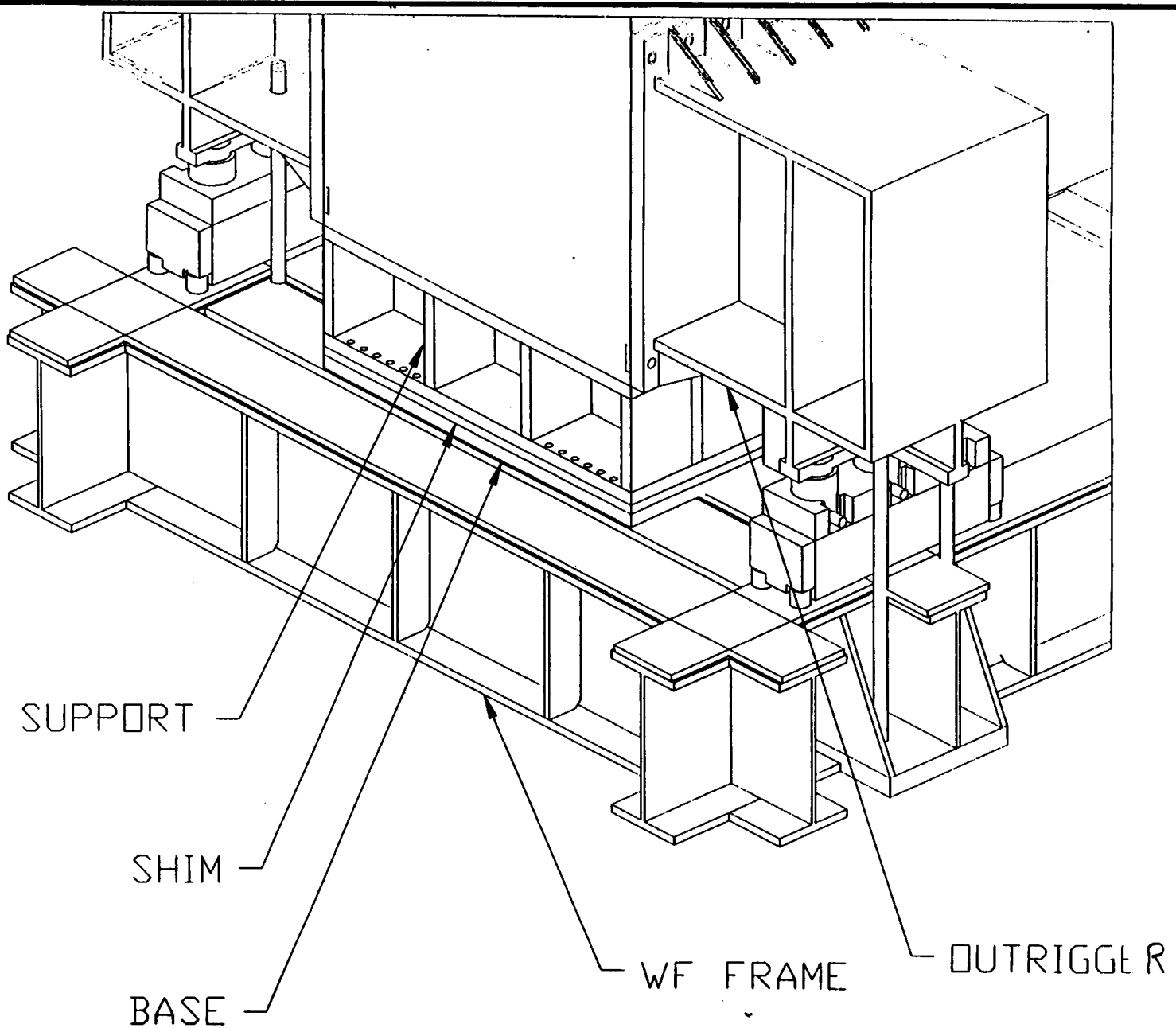
Central magnet mounting frame



Mounting frame

- Wide flange beam weldment for permanent mounting
- Distributes concentrated loads from central magnet
- Raises effective floor level, lowering CG of central magnet
- At same level as transport tracks
- Anchored to floor with concrete anchor studs
- T1 hardened plates provide rolling surface

Mounting Detail



Central Magnet transport system

- Outriggers are bolted and keyed to the lower flux return yoke to stabilize the load

- Each of four outriggers is lifted by a jack-roller combination
  - contains three 100 ton jacks
  - horizontal motion element: Hillman rollers

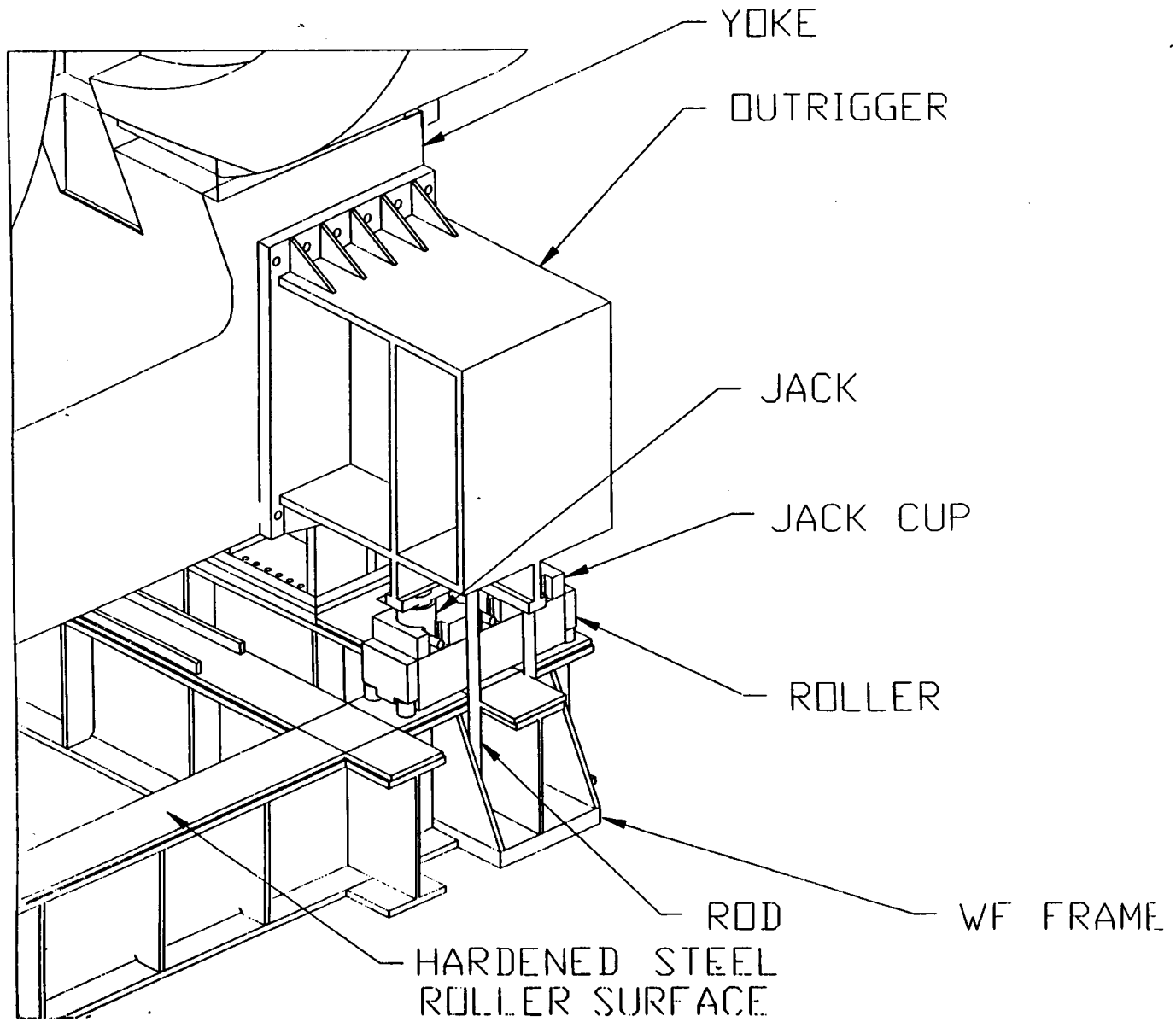
- Jacks assure balanced load sharing between outriggers

- Modular track system (reinforced I-beams) is shimmed level on the hall floor and provides a reliable track for rollers

- Hydraulic rams push/pull transporters horizontally on tracks

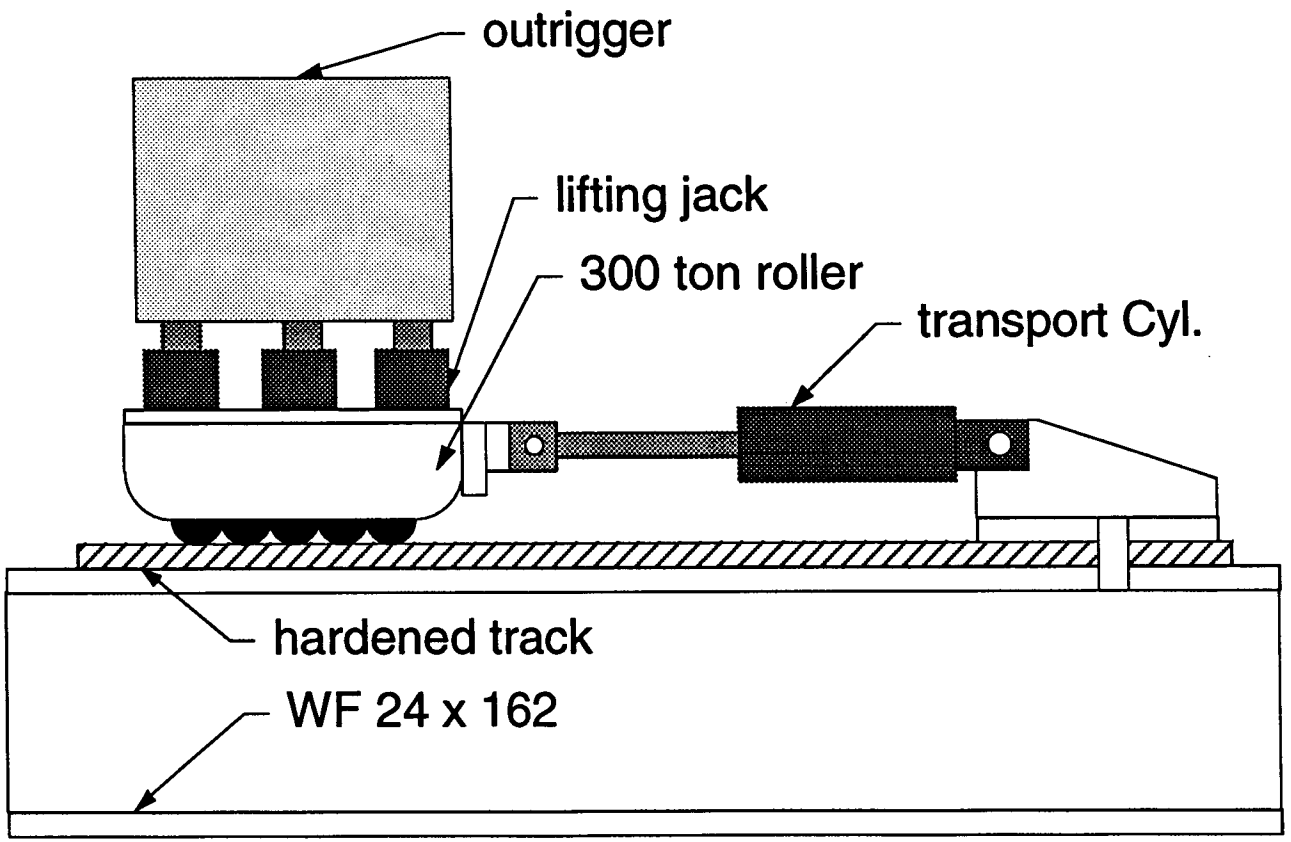
- Earthquakes not allowed during transport

Transport system elements



JMB-31
4/29/93

Central Magnet Assy. : Transport Components



Outrigger stabilization

1) Bolt down main supports to support frame

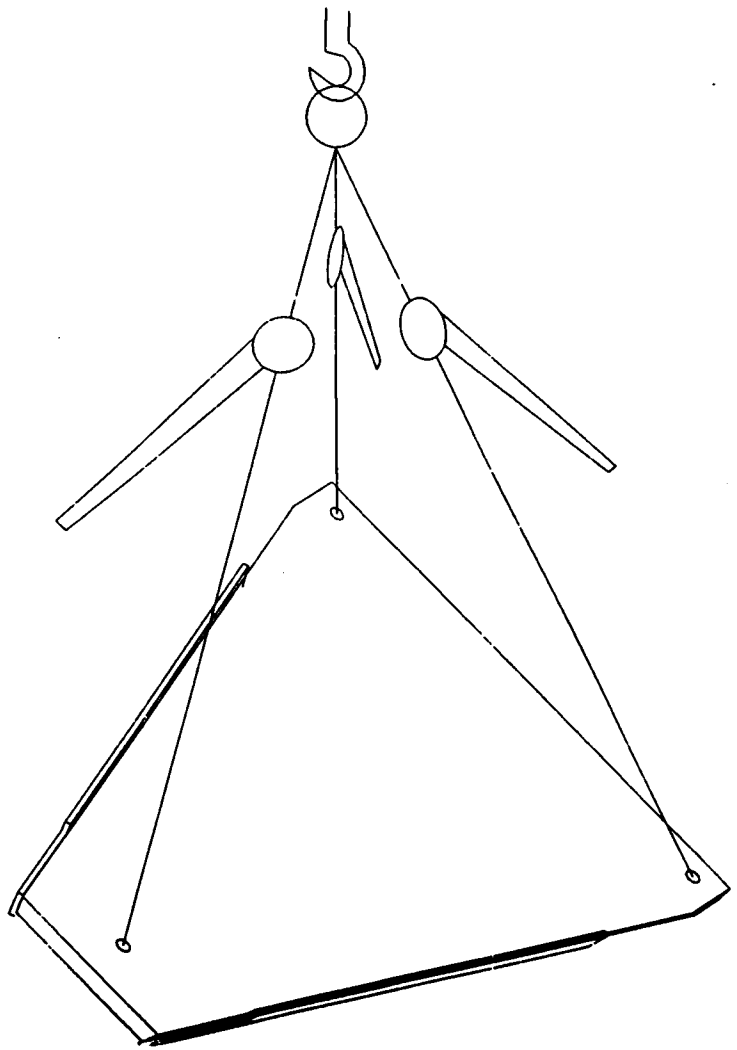
2) Extend transporter hydraulic cylinders, preload outriggers

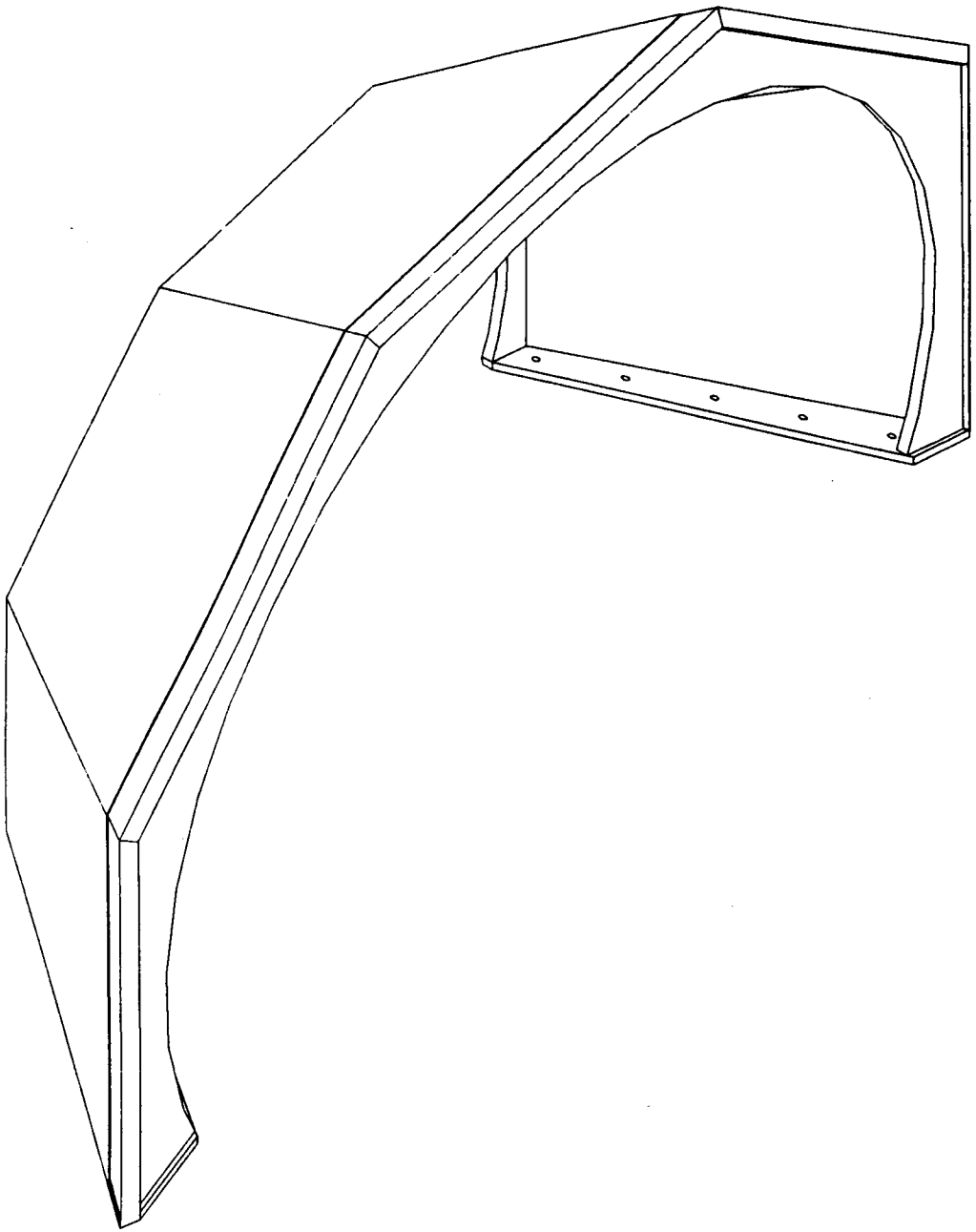
3) Lock cylinders, disengage hydraulic system

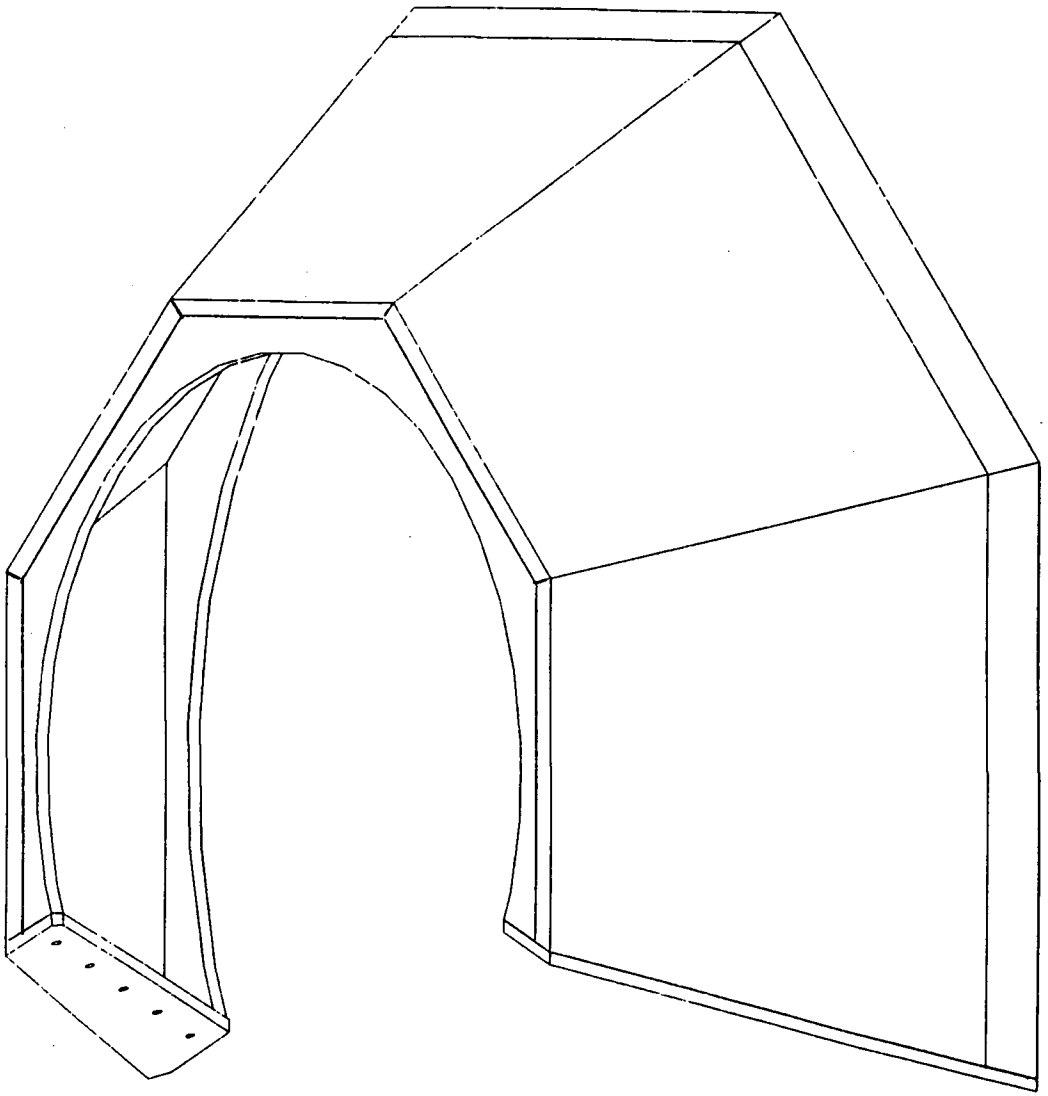
4) Tension hold down studs

Upper lampshade rigging

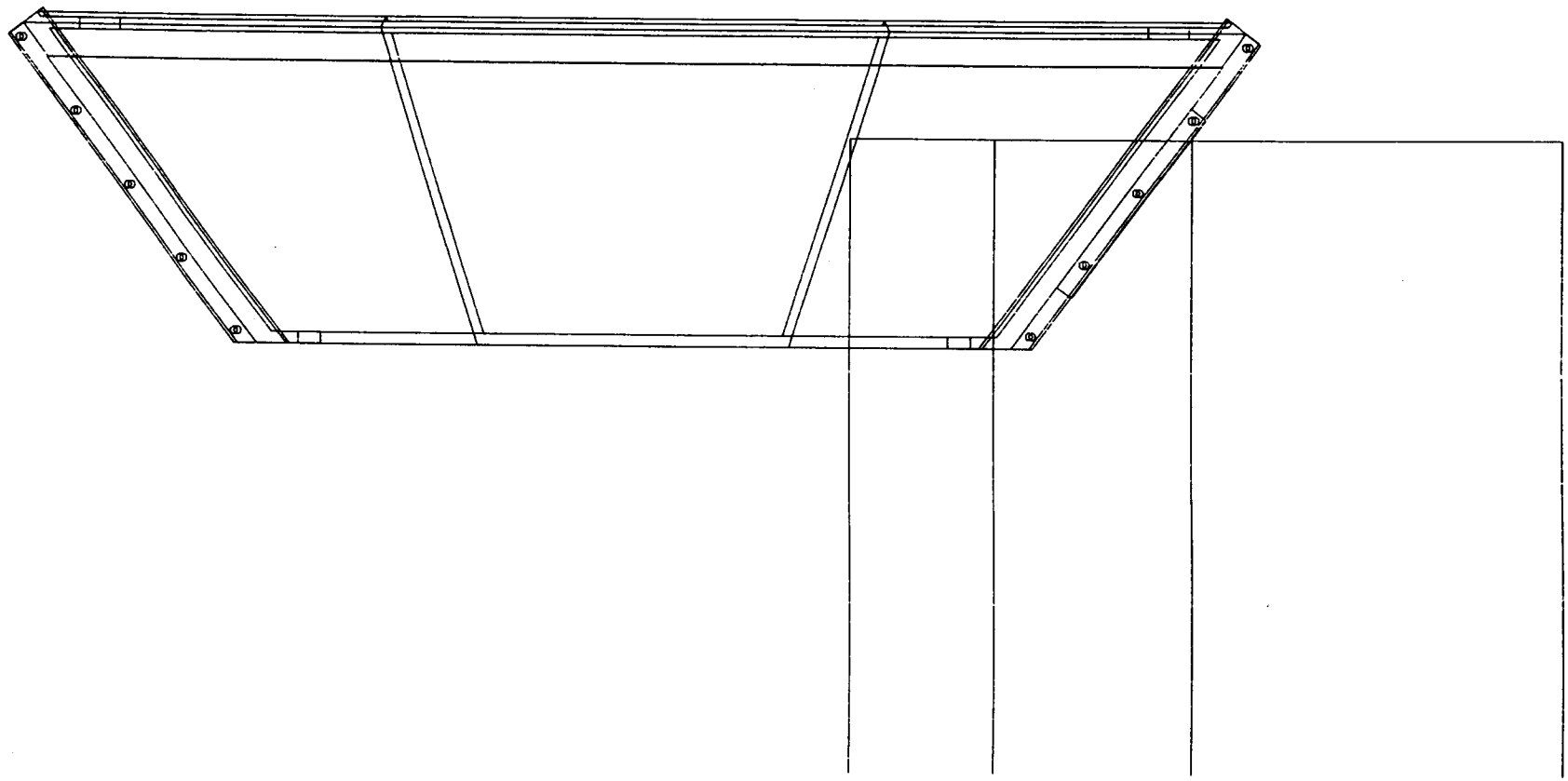
- Use swivel eyes in tapped holes in lampshade
- Use three point come alongs on crane hook to adjust angle







Interference of teacup flange to RICH



JMB
7/28/93

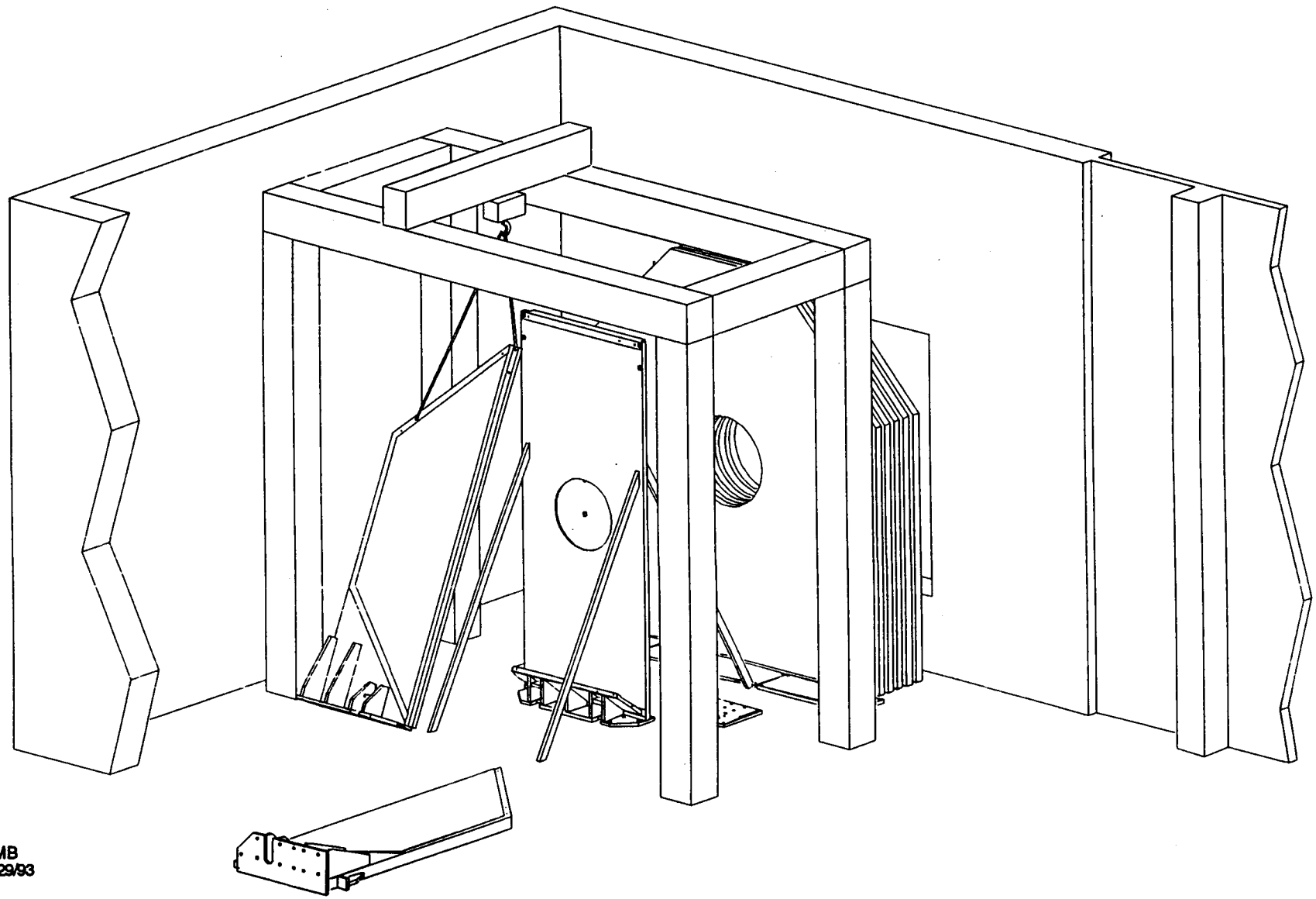
Hall Assembly

- May require muon system assembly away from muon ID due to space constraints. This will require a horizontal move after assembly.

- Performed by rigging team with specialized equipment

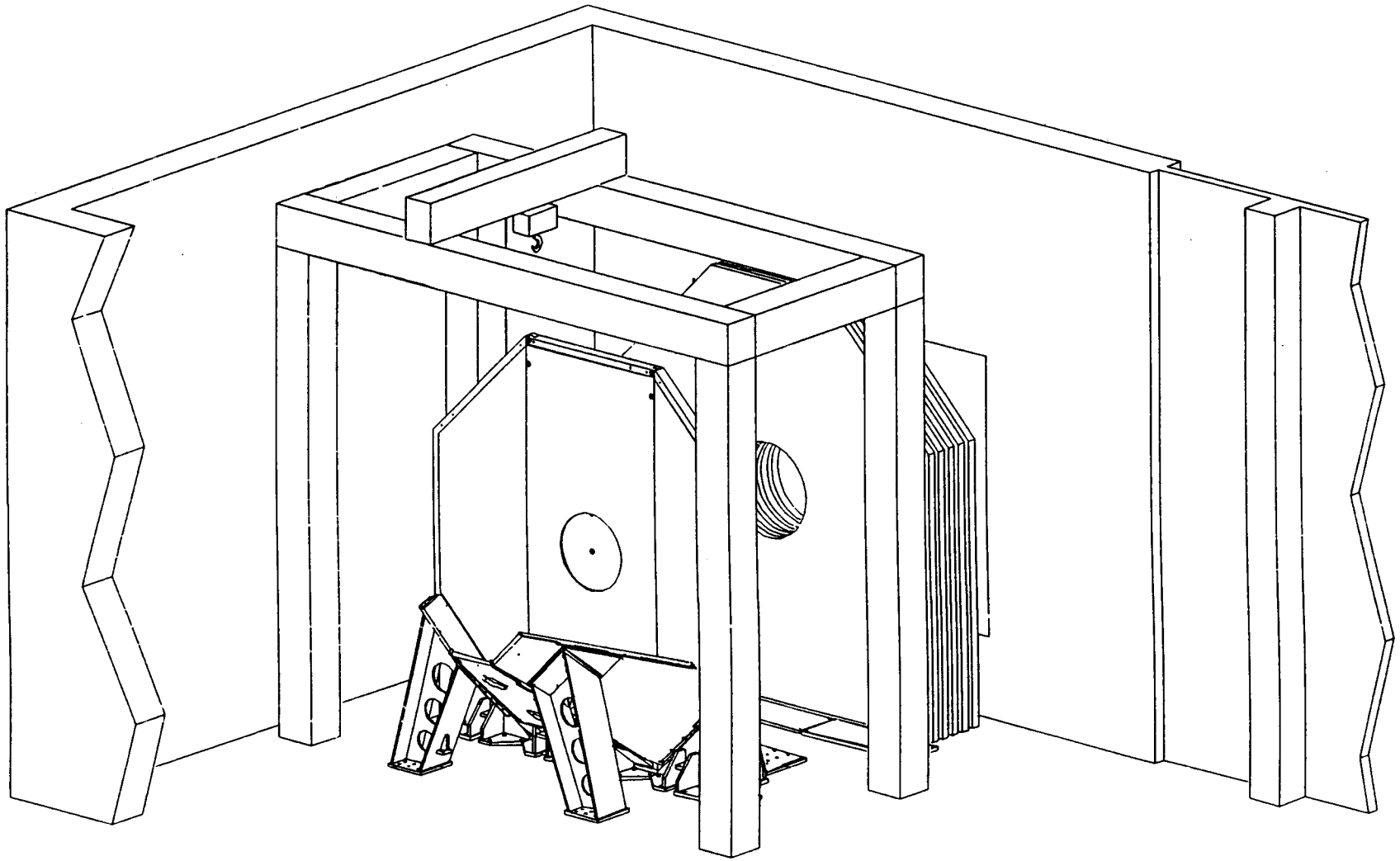
- Heavy lift jacking frame required
  - portable, erected on site
  - many types available for different applications

Hall Assembly: Muon back plate erection



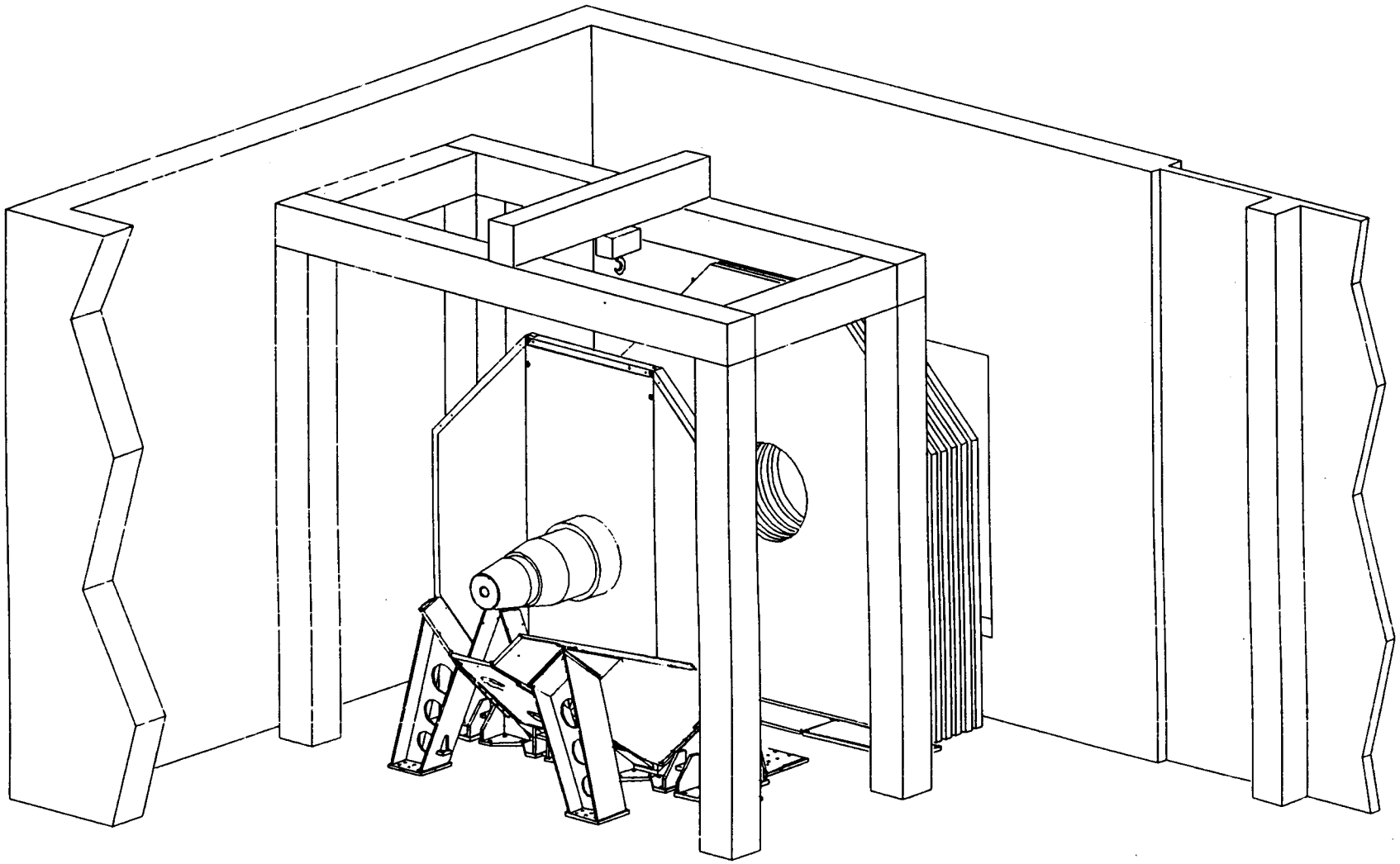
JMB
7/29/93

Hall Assembly: Bottom lampshade erection



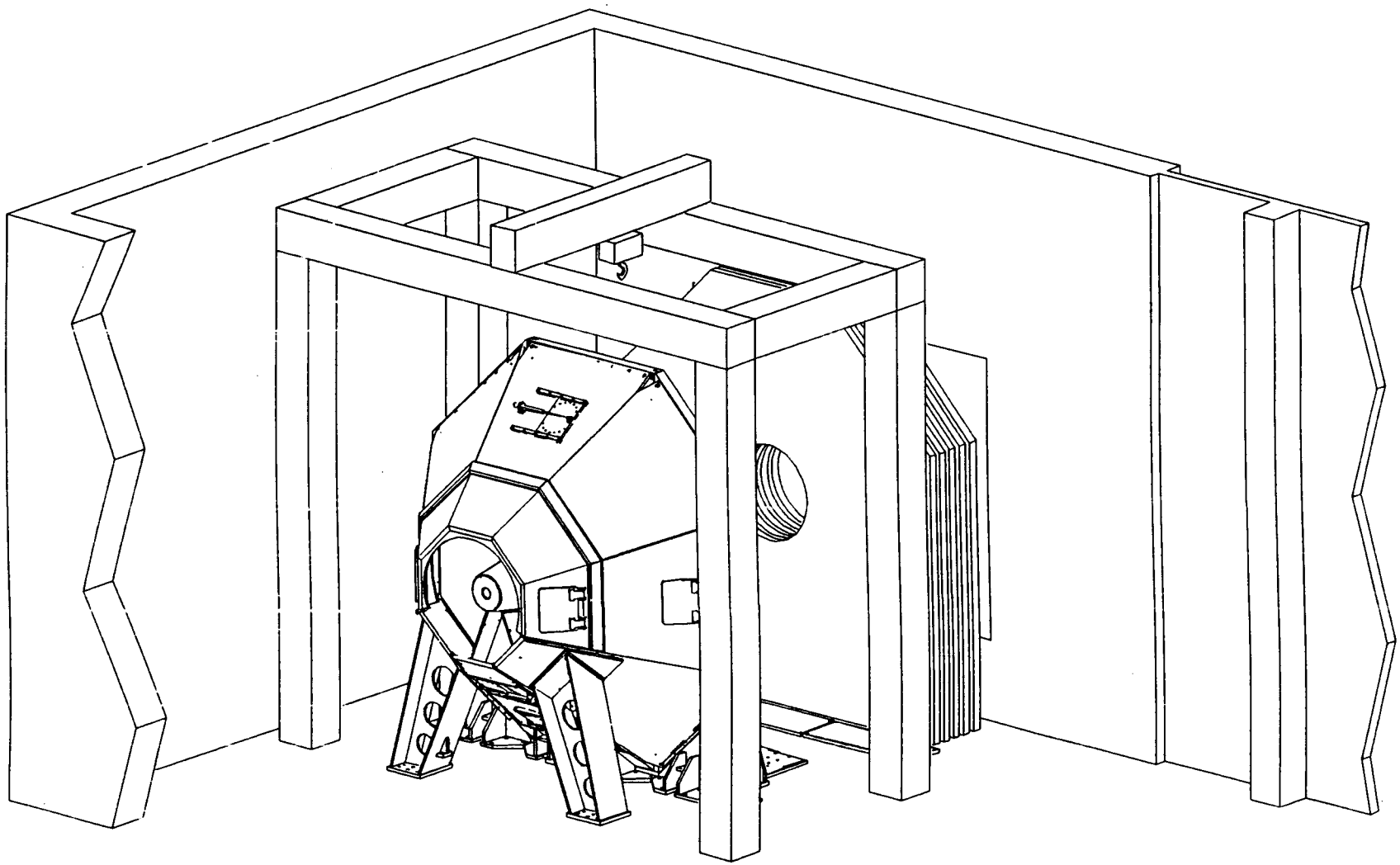
JMB
7/29/93

Hall Assembly: Piston and fins added



JMB
7/29/93

Hall Assembly: Complete muon system



JMB
7/29/93

Open issues under investigation

- Muon magnet penetration sizes, locations
- Muon magnet interface to muon detector
- Muon piston interface to beam-beam counter
- Blessing on floor interface from BNL plant engineering
- Items to be included in purchase order to Russia
- Assembly sequence
- Extent of permissable floor modifications
- Availability of cranes for lampshade removal
- Track design to accomodate RICH detector carriage